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THE AMERICAN FISHERIES SOCIETY

Organized 1870 **Incorporated 1910**

The Society was organized to promote the cause of fish culture; to gather and diffuse information of a scientific character; and to unite and encourage those interested in fish culture and fishery problems.

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[1]Elected by the membership.
[2]Each member serves for 5 years; one new member is appointed each year by the incoming President.

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[3]Appointed by the President-elect, in accordance with a motion adopted by the membership.

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The first meeting of the Society occurred December 20, 1870. The organization then effected continued until February, 1872, when the second meeting was held. Since that time there has been a meeting each year, as shown below. The respective presidents were elected at the meeting, at the place, and for a period shown opposite their names, but they presided at the subsequent meeting.

1.	William Clift	1870-1872	New York, N. Y.
2.	William Clift	1872-1873	Albany, N. Y.
3.	William Clift	1873-1874	New York, N. Y.
4.	Robert B. Roosevelt	1874-1875	New York, N. Y.
5.	Robert B. Roosevelt	1875-1876	New York, N. Y.
6.	Robert B. Roosevelt	1876-1877[1]	New York, N. Y.
7.	Robert B. Roosevelt	1877-1878	New York, N. Y.
8.	Robert B. Roosevelt	1878-1879	New York, N. Y.
9.	Robert B. Roosevelt	1879-1880	New York, N. Y.
10.	Robert B. Roosevelt	1880-1881	New York, N. Y.
11.	Robert B. Roosevelt	1881-1882	New York, N. Y.
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13.	James Benkard	1883-1884	New York, N. Y.
14.	Theodore Lyman	1884-1885	Washington, D. C.
15.	Marshall McDonald	1885-1886	Washington, D. C.
16.	W. M. Hudson	1886-1887	Chicago, Ill.
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18.	John Bissell	1888-1889	Detroit, Mich.
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20.	Eugene G. Blackford	1890-1891	Put-in-Bay, Ohio
21.	James A. Henshall	1891-1892	Washington, D. C.
22.	Herschel Whitaker	1892-1893	New York, N. Y.
23.	Henry C. Ford	1893-1894	Chicago, Ill.
24.	William L. May	1894-1895	Philadelphia, Pa.
25.	L. D. Huntington	1895-1896	New York, N. Y.
26.	Herschel Whitaker	1896-1897	New York, N. Y.
27.	William L. May	1897-1898	Detroit, Mich.
28.	George F. Peabody	1898-1899	Omaha, Nebr.
29.	John W. Titcomb	1899-1900	Niagara Falls, N. Y.
30.	F. B. Dickerson	1900-1901	Woods Hole, Mass.
31.	E. E. Bryant	1901-1902	Milwaukee, Wis.
32.	George M. Bowers	1902-1903	Put-in-Bay, Ohio
33.	Frank N. Clark	1903-1904	Woods Hole, Mass.
34.	Henry T. Root	1904-1905	Atlantic City, N. J.
35.	C. D. Joslyn	1905-1906	White Sulphur Springs, W. Va

[1] A special meeting was held at the Centennial Grounds, Philadelphia, Pa., October 6 and 7, 1876.

36.	E. A. Birge	1906-1907	Grand Rapids, Mich.
37.	Hugh M. Smith	1907-1908	Erie, Pa.
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42.	Charles H. Townsend	1912-1913	Denver, Colo.
43.	Henry B. Ward	1913-1914	Boston, Mass.
44.	Daniel B. Fearing	1914-1915	Washington, D. C.
45.	Jacob Reighard	1915-1916	San Francisco, Calif.
46.	George W. Field	1916-1917	New Orleans, La.
47.	Henry O'Malley	1917-1918	St. Paul, Minn.
48.	M. L. Alexander	1918-1919	New York, N. Y.
49.	Carlos Avery	1919-1920	Louisville, Ky.
50.	Nathan R. Buller	1920-1921	Ottawa, Canada
51.	William E. Barber	1921-1922	Allentown, Pa.
52.	Glen C. Leach	1922-1923	Madison, Wis.
53.	George C. Embody	1923-1924	St. Louis, Mo.
54.	Eben W. Cobb	1924-1925	Quebec, Canada
55.	Charles O. Hayford	1925-1926	Denver, Colo.
56.	John W. Titcomb	1926-1927	Mobile, Ala.
57.	Emmeline Moore	1927-1928	Hartford, Conn.
58.	C. F. Culler	1928-1929	Seattle, Wash.
59.	David L. Belding	1929-1930	Minneapolis, Minn.
60.	E. Lee LeCompte	1930-1931	Toronto, Canada
61.	James A. Rodd	1931-1932	Hot Springs, Ark.
62.	H. S. Davis	1932-1933	Baltimore, Md.
63.	Fred A. Westerman	1933-1934	Columbus, Ohio
64.	E. L. Wickliff	1934-1935	Montreal, Canada
65.	Frank T. Bell	1935-1936	Tulsa, Okla.
66.	A. G. Huntsman	1936-1937	Grand Rapids, Mich.
67.	I. T. Quinn	1937-1938	Mexico City, Mexico
68.	Fred J. Foster	1938-1939	Asheville, N. C.
69.	T. H. Langlois	1939-1940	San Francisco, Calif.
70.	James Brown	1940-1941	Toronto, Canada
71.	John Van Oosten	1941-1942	St. Louis, Mo.
72.	John Van Oosten	1942-1943	(No meeting.)[2]
73.	John Van Oosten	1943-1944	(No meeting.)[3]

[2]The annual meeting scheduled to be held in New Orleans La., was cancelled because of the war emergency.

[3]No annual meeting scheduled because of the war

In Memoriam

Thomas S. Jones, Louisville, Kentucky

Jacob E. Reighard, Ann Arbor, Michigan

W. H. Safford, Northville, Michigan

Allan G. Siems, St. Paul, Minnesota

W. T. Thompson, Bozeman, Montana

John Wagner, Philadelphia, Pennsylvania

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PART I
REPORTS

REPORTS OF OFFICERS

THE CANCELLATION OF THE SEVENTY-THIRD ANNUAL MEETING OF THE AMERICAN FISHERIES SOCIETY

JOHN VAN OOSTEN, *President*

The meeting of the Society scheduled to be held in New Orleans, Louisiana, during September 1942 was cancelled because of conditions imposed by the war. New Orleans is at a considerable distance from the center of population of the United States, making it difficult for members to travel there under various wartime restrictions; also, New Orleans had become very congested due to the rapid growth in its population occasioned by accelerated war activities in the area.

Although the Executive Committee realized that a meeting during 1943 on the scale of those held during the years prior to the war could not be proposed, many strong arguments were advanced in favor of a 1943 meeting even though the attendance would be small.

The Executive Committee, by means of a circular letter mailed on June 21, 1943, requested the opinions of the members concerning a meeting in September, possibly at Pittsburgh, Pennsylvania. The results of the poll were overwhelmingly in favor of cancelling the 1943 meeting. The number of members who indicated that they would attend the meeting, if one were scheduled, was surprisingly small. The results of a similar poll of the members of the International Association of Game, Fish and Conservation Commissioners, which for many years has held joint meetings with the American Fisheries Society, were comparable. Therefore, the Executive Committees of both organizations decided to cancel their 1943 joint meeting. In informing the members of the American Fisheries Society of this decision it was indicated that the Society would publish a Volume of the TRANSACTIONS even though a meeting was not held. The response to the call for manuscripts fortunately has resulted in the publication of a Volume which compares favorably in quality and size with those issued during previous years. The cooperation of the members in the issuance of such a good volume during these difficult times indicates that the interest in the Society and its task of furthering theoretical and practical knowledge of the fishery sciences has not diminished.

REPORT OF THE SECRETARY-TREASURER
For the Year 1942-1943

R. P. HUNTER

For the second year the effects of the war are reflected in an adverse trend in the membership statistics of the Society. At the close of the fiscal year we dropped 70 active members, 1 club and dealer, 2 State

memberships, and 2 libraries for non-payment of dues. Resignations were submitted by 9 active members, 1 State, 1 club and dealer, and 1 library. Six members were lost through death. The total loss was 93. During the year the Society gained 41 active members (including 5 reinstatements), 1 club and dealer, 1 State (reinstatement), 2 life members (1 transferred from active membership), and 1 library. The total of new members was 46, and the net loss in membership for the year 1942-1943 was 47.

The treasurer's report follows:

TREASURER'S REPORT

July 1, 1942—June 30, 1943

General Fund

RECEIPTS		
Balance on hand July 1, 1942		$1,037.64
Annual dues		
Individuals:		
For the year 1940-1941	$ 18.00	
1941-1942	162.00	
1942-1943	879.00	
1943-1944	213.50	
1944-1945	3.00	1,275.50
Life		100.00
Libraries:		
For the year 1941-1942	12.00	
1942-1943	66.00	78.00
Clubs and Dealers:		
For the year 1941-1942	5.00	
1942-1943	115.00	120.00
State Memberships:		
For the year 1940-1941	20.00	
1941-1942	100.00	
1942-1943	500.00	
1943-1944	20.00	640.00
Exchange on checks		.73
Sale of *Transactions*		281.67
Sale of reprints		
1940 *Transactions*	37.61	
1941 *Transactions*	267.57	305.18
Sale of Index		16.50
Transferred from Permanent Fund for photostating and binding volumes of *Transactions*		187.00
Total receipts		$4,042.22

DISBURSEMENTS

Transactions		
1941, Vol. 71		
Reprints	$ 287.44	
Printing	1,600.59	$1,888.03
Stationery and printing		70.25
Exchange on checks		2.98
Postage		70.14
Office supplies		3.00
General expense		.50
Rental safe deposit box		6.00
Refund		
Transactions	2.00	
Membership	3.00	5.00
Insurance		13.50
Clerical and secretarial expense		
R. P. Hunter	100.00	
Ethel M. Quee	300.00	
Miscellaneous	6.00	406.00
Premium on fidelity bond		18.75
Total disbursements		$2,484.15
Total receipts General Fund	$4,042.22	
Total disbursements General Fund	2,484.15	$1,558.07
Balance on hand, July 1, 1943	$1,558.07	
Balance in Petty Cash Fund	5.00	
Balance on hand July 1, 1943	$1,563.07	

Permanent Fund[1]

RECEIPTS

Balance on hand July 1, 1942		$1,495.47
Interest on Savings Account	$ 20.02	
Interest and principal Mortgage Certificates	220.56	240.58
Total		$1,736.05

DISBURSEMENTS

Transferred to General Fund for photostating and binding volumes of *Transactions*	$ 187.00
Balance on hand July 1, 1943	$1,549.05

INVENTORY

Par value of certificates other than Government Bonds	5,000.00
Par value of 10 shares Commonwealth Southern pfd.[2]	1,000.00
Par value of Government Bonds	1,650.00
Total	$9,199.05

[1]The list of securities owned by the American Fisheries Society as of July 1, 1940, was published in Vol. 70, pp. 24-25 of the *Transactions*. No changes in holdings have occurred since that date.

[2]The current value of the 10 shares of Commonwealth Southern, pfd., par value $100.00, as of July 1, 1943 was $652.50.

PART II
PAPERS

THE EXPERIMENTAL INTRODUCTION OF SMALLMOUTH BLACK BASS INTO LAKES OF THE PRINCE ALBERT NATIONAL PARK, SASKATCHEWAN

DONALD S. RAWSON

Department of Biology, University of Saskatchewan, Saskatoon, Saskatchewan

ABSTRACT

The introduction of smallmouth black bass (*Micropterus dolomieu*) into lakes of Saskatchewan has been attempted unsuccessfully over a period of forty years but never in freshwater lakes of the Churchill River drainage. The need for better game fish in the newly established Prince Albert National Park led to the present experiment which was carried on under close observation. Adult bass were brought from Eastern Canada, confined in rearing enclosures screened off in protected bays and provided with artificial nests. Stocking was begun in 1936 and continued for five summers with some interruption. A total of 1,500 adults was transported and 260,000 fry have been reared. These have been released in Waskesiu and the Heart Lakes.

Investigations in 1942 showed that the adult bass had survived in fair numbers and were spawning in the Heart Lakes. No evidence was obtained that the fry released in the lakes have been reaching maturity. The abundance of piscivorous fish and the immature stage at which these fry were planted are suggested as factors contributing to a high mortality. Experience at Waskesiu Lake suggests that the larger, deeper lakes of this region are marginal as to the temperature toleration of the species. Shallower waters, such as the Heart Lakes may prove quite suitable for smallmouth bass.

The method of rearing bass in natural enclosures and the successful use of this method has been reported by the author (Rawson, 1938). Further experience with this procedure has demonstrated that egg and fry losses resulting from falling temperatures, occur in these enclosures as they do in the usual type of rearing pond. It has also shown the desirability of enclosures where the fry might be fed to avoid planting them in an immature condition.

INTRODUCTION

After a survey in 1928 of the game fish possibilities of lakes in the newly established Prince Albert National Park, it was recommended that an attempt be made to introduce the smallmouth black bass. The program for the first year included the transfer of adult bass early in the season and confining them in screened enclosures to see whether they would spawn in their new environment. This was done in 1936 and the successful use of natural rearing enclosures was reported (Rawson, 1938). The remainder of the stocking program was somewhat delayed by difficulties in obtaining breeding stock, but it was completed in 1942. This is a final account of the experiment which had the twofold purpose of testing the efficiency of natural enclosures and the possibility of establishing smallmouth bass in these waters.

THE PLAN FOR STOCKING

The initial survey of these lakes revealed an abundance of fish among which the pickerel, *Stizostedion vitreum*, the pike, *Esox lucius*,

and the lake trout, *Cristivomer namaycush*, were the chief game species. Since none of these is regarded as a first-class game fish, it was decided that the smallmouth bass would be a desirable addition. The choice of this species was made with due regard to the physical and biological conditions in the lakes especially water temperatures, food supply and spawning grounds. While some of the lakes in this area may be considered as physically suitable for the introduction of game trout, it was thought that the bass was more likely to succeed in competition with the numerous piscivorous fish already present.

The original distribution of smallmouth bass is not accurately known but it is believed to have extended into northern Minnesota (Hubbs and Bailey, 1938). It is reported[1] to have been planted in a small lake near the Lake of the Woods in 1903 and it became established in the lake about 1915. The Prince Albert Park lies some 600 miles northwest from the Lake of the Woods area. Since the mean annual and mean summer temperatures are similar in the two areas and since both lie within the Canadian Life Zone, the proposed introduction seemed feasible.

Numerous attempts to introduce smallmouth and largemouth bass into lakes of the Prairie Provinces have been made in the years 1900 to 1942. Plantings have been made in three lakes in Manitoba with success in one, in 16 lakes in Saskatchewan with no success and 13 lakes in Alberta with no success. In several of these lakes, plantings were made three and four times over a period of 15 years.

The successful introduction listed for Manitoba was in West Hawk Lake, a short distance west of Lake of the Woods. From this lake the bass have moved downstream to establish themselves in Caddy Lake. From the Lake of the Woods bass have moved down the Winnipeg River and during the summer of 1943 several were taken from Lake Winnipeg.[2] These extensions of the range of the bass all occurred in water lying on Precambrian rocks of the Canadian Shield area. Two attempts to introduce bass into Lake Killarney in southwest Manitoba resulted in failure.

Recent examinations of the 16 Saskatchewan lakes in which bass had been planted revealed that all were somewhat saline. The total solid content of their waters ranged from 412 to 7,870 p.p.m. whereas 300 p.p.m. is commonly considered the upper limit of fresh waters. Waskesiu and Heart Lakes of the Prince Albert National Park are in the Churchill River Drainage and, like most of the lakes in this area, they have fresh water with total solids about 180 p.p.m. Since this was the first attempt to introduce bass into the drainage area and since attempts in the southern part of the province had failed, it was desirable to plan the experiment with special care. The stocking method was devised to allow a maximum of control and observation in the

[1]Twenty-third Annual Report, Ontario Game and Fisheries Department, 1929.

[2]Personal communication, A. G. Cunningham, Director of Game and Fisheries, Winnipeg, Manitoba.

hope that reasons might be determined for the success or failure of the experiment. The proposal to continue planting for five years was made on the assumption that the survivors of those reared in the first season might reach maturity during this period and also in the hope that continued planting would increase the chances of crowding a new species into the fish population of the lakes.

The Progress of Planting

The first transfer of bass to Waskesiu Lake was an abortive attempt in August, 1931, when 25 parent bass were shipped by air from Kenora, Ontario. Thirteen bass died in transit and the remaining 12 were kept in a screened enclosure, fed and released in good condition on September 20. The shipment was made too late in the season to provide any test of the suitability of the lake for spawning.

The first real progress was made in 1936 when 300 adult bass were brought from Spanish, Ontario, on the north shore of Lake Huron. The fry reared numbered 85,000 and the adults and fry were distributed in Waskesiu and Heart Lakes as indicated in Table 1. An account of the method of transfer, rearing and planting was published in this journal as mentioned above.

In 1937 it was not possible to obtain breeding stock but in 1938 a shipment of 488 bass arrived on June 2. These had been obtained near Magog Hatchery in the vicinity of Sherbrooke, Quebec, and had been shipped more than 2,000 miles. Unfortunately, most of these fish were of small size and immature. Eighty-five per cent were less than 7½ inches in length. Only a few spawned and the fry added to the lake numbered only 1,200.

In 1939 a second shipment of 155 bass was brought from Spanish, Ontario. Unfavorable temperature conditions interfered with spawning but 38,000 fry were planted, 9,000 of these in the Heart Lakes. Twenty-five adults were retained in a special enclosure in an attempt to keep them through the winter and use them for rearing in the following summer. The screen enclosure survived the winter without damage from the ice but an opening developed in the deeper water through which most of the bass escaped. With some improvement in the construction it would seem quite feasible to carry adult bass through the winter in screened enclosures.

In 1940 it was again impossible to obtain breeding stock but in 1941 a fourth shipment was received, this time from the Bay of Quinte near Belleville, Ontario. Rearing was successful and 97,000 fry were distributed.

In 1942 the final shipment arrived from Belleville, Ontario, on May 21. It included 336 bass which were placed in five enclosures for rearing. Unfavorable weather with prolonged low temperatures hampered the rearing and only 38,000 fry were planted.

The total number of bass released is indicated in Table 1 as 1,279

TABLE 1.—*Summary of smallmouth bass plantings in Waskesiu and Heart Lakes*

Year	Adult Bass shipped	Adults dead during shipment	Adults dead during first month	Adults released after rearing	Adults moved to Heart Lakes	Adults left in Waskesiu	Total fry reared	Fry transferred to Heart Lakes	Fry released in Waskesiu
1931	25	12	0	13	0	13	0	0	0
1936	298	0	11	287	21	266	85,000	19,000	66,000
1938	[1]487	24	8	455	0	378	1,200	0	1,200
1939	155	16	35	104	77	104	38,650	9,250	29,400
1941	336	0	1	335	14	321	97,100	5,900	91,200
1942	336	0	2	334	137	197	38,200	6,400	31,800
Toatls	1637	52	57	1528	249	1279	260,150	40,550	219,600

[1]85 per cent of these were immature, less than 7½ inches long.

adults and 219,000 fry in Waskesiu, 249 adults and 10,000 fry in the Heart Lakes. These figures may convey an impression of heavy planting but such an impression is not justified when the large area of the lakes and other factors are taken into account. Since the first of the adult fish were released in 1936 many of that shipment and a good many from subsequent shipments would be dead in 1942. The smallmouth bass is usually reported as reaching maturity in the northern part of its range in from four to six years (Hubbs, 1938). In a sample of 1,451 bass from Wisconsin Lakes (Bennett, 1938), the average life span of fish which reached the fifth year was about 6.5 years. About 5 per cent of the mature fish lived to an age of 10 years and only 1 per cent to 12 years. It is also evident that a large proportion of the fry released would be dead in 1942.

In the absence of information as to the rates of mortality among adults and fry, the records of planting do not give much indication of the present population. It might be more useful to state that the planting in Waskesiu Lake was equivalent to an average of 183 adults and 31,400 fry in each of the 7 years, 1936 to 1942. The survival of fry to the adult state is often assumed to be of the order of 5 per cent. On this basis the planting of 183 adults would be equivalent to 3,660 fry and the total annual planting could be estimated as 35,060 fry. Waskesiu Lake has an area of 17,000 acres. Thus the annual planting is equal to 2 fry per acre which must be regarded as a very light planting, especially in a lake heavily populated with piscivorous fish. Similarly, the planting in the Heart Lakes has been equal to an average of 35 adult and 5,800 fry per year which amounts to between three and four fry per acre. This is nearly twice the rate of planting in Waskesiu Lake but it is still relatively light.

Temperature Effects on Bass Rearing

Rearing enclosures of the type described in the earlier paper were employed in each of the 5 years. In 1938, because of the immaturity of most of the stock, only 1,200 fry were reared but in the remaining years the number ranged from 38,000 to 97,000 as indicated in Table 1. The variation in the number reared is attributed mostly to temperature conditions which in 2 of the years were quite unfavorable.

Temperature records were kept at the rearing enclosures throughout the spawning period in each of the 5 years. These records include the temperature of the air, surface water and of the water at nest level, *i.e.* approximately 18 inches below the surface and close to the bottom. In 1938 there were so few mature bass that it was not possible to correlate the spawning with temperature conditions. In the other 4 years the temperature level and changes in temperature were seen to be responsible for the onset of spawning, the rate of development and in 2 of the years, for considerable losses in eggs when low temperatures occurred during the incubation period and many nests were deserted. In Figure 1 the temperatures at nest level in the bay at Waskesiu

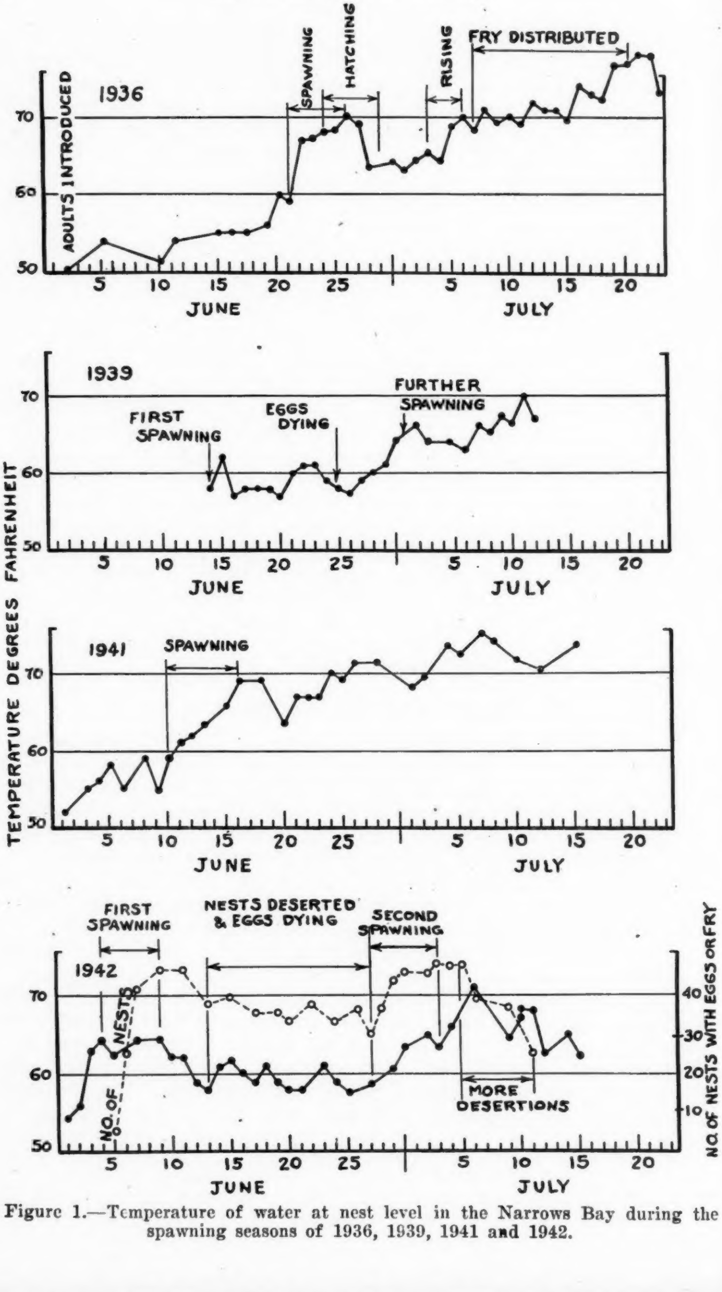

Figure 1.—Temperature of water at nest level in the Narrows Bay during the spawning seasons of 1936, 1939, 1941 and 1942.

Narrows are shown in chart form for the years 1936, 1939, 1941 and 1942. Along with the temperature curve for 1942 is plotted the number of nests with living eggs or fry.

In 1936 temperature conditions were favorable for rearing bass. The sudden rise from about 55° to 67° F. in the period June 19 to 22 stimulated the spawning and by June 23 more than half the eggs had been laid. The nest-level temperature continued between 67° and 69° F. for 6 days, by which time hatching was well advanced. A drop in temperature of about 5° between June 28 and July 4 may have delayed the rising of the fry to some slight extent, but it was apparently not great enough to cause any desertions or death of eggs. From July 5 to 20, the water continued to warm, the fry developed rapidly and were distributed in this period. A total of 32 nests had been formed and of these 23 produced considerable numbers of fry.

In 1939, as may be seen in Figure 1, the temperature conditions were quite different. A brief rise on June 15 to 62° F. was apparently enough to initiate some spawning, but continued cool water made development slow, and numerous eggs died about June 24 and 26. The gradual rise from 57.5° on June 26 to 66° F. on July 2, stimulated some further spawning, but most of the nests were small, many were deserted, and fry production was poor. Of the 33 nests in which eggs were laid, 23 were abandoned and the remaining 10 produced only moderate numbers of eggs. This occurred in spite of the fact that the breeding stock was excellent and had been handled in the same way as that used in 1936.

In 1941, temperature conditions were again favorable for rearing. The temperature remained above 50° from May 18 on; and rose to nearly 60° F. in the period June 5 to 10. Spawning began on June 9 and was three-quarters over by June 13. The temperature continued to rise and remained between 67° and 73° F. from June 15 to July 5, during which time all the eggs hatched, the fry rose and most of the fry were distributed. There was no significant cooling of the water after the eggs had been deposited which explains the high percentage of successful nests in this season. Of 72 nests in which eggs were laid, only 15 were abandoned, but the remainder produced smaller numbers of fry per nest than those of 1936, probably because of crowding of the adults as discussed below.

In 1942, the initial rise in temperature occurred early, with nest level temperatures going from 54° to 64.5° F. between June 1 and 4. This temperature was maintained for most of a week during which time a large number of nests were made as indicated in Figure 1. On June 10, the temperature began to fall and cool weather set in. The temperature hovered around 60° F. for the next 2 weeks. During this period some new nests were formed when the temperature rose slightly but others were deserted and the eggs died. On June 27 the temperature began to rise again, initiating a second spawning period and since it stayed higher than 65° F. for most of the next two weeks, a

moderate number of fry were reared. About 60 per cent of the fry were from the earlier spawning period June 5 to 9 and the remaining 40 per cent from the second period, June 26 to July 3. No fry survived from the irregular spawning between these two periods. The temperatures in the latter half of June 1942 were almost the same as those in 1939, but the earlier rise to 64° F. in June 1942 started spawning very early and the ensuing cold period thus caused great damage.

Summarizing the above records it will be seen that there were 2 good years of rearing and 2 lean years. In the good years, 1936 and 1941, there was a sharp initial rise and the temperature was maintained long enough to allow hatching and rising of the fry without serious losses. In 1941 the season was almost two weeks earlier than in 1936, but the general trend of temperatures was much the same. The 2 poor years, 1939 and 1942, were years of prolonged low temperatures. In 1939, it was too low to initiate much spawning until the first of July. In 1942, spawning was begun early in June, but subsequent cold weather resulted in great losses. It is unfortunate that the bass received in 1938 was mostly immature including only a few spawning individuals. Temperature records show that the season 1938 was as good as 1941, and better than 1936, the other good year.

In a general way, it is clear from the above observations that spawning of smallmouth bass is normally stimulated by a fairly quick rise in water temperature in the neighbourhood of 60° F. For successful development, a period of two or three weeks in which the temperature is maintained about 65° F. or higher is required. Any considerable drop in temperature and especially any prolonged period during which the temperature drops below 60° F., results in desertion of the nests by the males, death of eggs, and to a lesser extent, death of fry which have not yet risen from the nests.

An Appraisal of the Enclosure Method

The use of screened enclosures with artificial nests has been highly satisfactory in most respects. Large numbers of fry have been reared and it has been possible to make the careful study of spawning and development of bass which was considered essential in an experimental introduction of this kind. The economy and convenience of the screened enclosures as compared with permanently constructed artificial rearing ponds has been recognized.

The two major difficulties or limitations of the method, as used at Waskesiu, were the uncontrolled temperature fluctuations and the need for distributing the fry at an early stage. It had been hoped that the temperature of the water in the screened enclosure would be tempered by its connection with the lake and thus the loss of eggs from falling temperatures might be reduced. It was indicated above that this expectation was not realized. It should be noted however that these lakes are probably near the northern limit for smallmouth bass and that in areas where bass are indigenous the screened enclosure

might still maintain better temperatures than artificial ponds. The second difficulty, of having to screen the nest when the fry begin to rise and thus to remove the parent male which would normally guard these fry for some weeks, is a limitation met with in regular hatchery procedure. The obvious solution would be the use of feeding ponds in which the young could be reared to a larger size prior to distribution. In 1936 a feeding enclosure was screened off as described in the earlier paper and satisfactory growth achieved using plankton netted from the lake to supplement the natural food of the pond. In 1939 a similar enclosure was used but the fry were not sufficiently uniform in size and the development of cannibalism made it necessary to distribute them early. The preparation and maintenance of several feeding enclosures would have been impossible with the funds and personnel available.

It was also noted that the crowding of adults is as undesirable in natural enclosures as it is in rearing ponds. In the years 1941 and 1942 the whole shipment of 336 adults was confined in 5 enclosures which the writer considered as suitable for 105 bass, *i.e.* 10 pairs in each enclosure plus an extra female. The result of this crowding is shown in Table 2. In 1936, 54 per cent of the pairs spawned while

TABLE 2.—*Information as to the success of nesting and the effects of crowding parent smallmouth bass in enclosures*

Year	Total fish enclosed	Total number of nests	Abandoned nests	Successful nests	Average number of fry per successful nest	Percentage of parents spawning successfully	Total fry reared
1936	85	32	9	23	3,700	54	85,000
1939	80	33	23	10	3,800	25	38,650
1941	336	72	15	57	1,700	34	97,000
1942	336	104	79	25	1,500	15	38,200

in 1941 with similar temperature conditions only 34 per cent spawned. In 1939 under unfavorable temperature conditions 25 per cent spawned and in 1942 under similar conditions only 15 per cent spawned.

SUCCESS IN STOCKING WASKESIU AND HEART LAKES

Some evidence of the survival of adult bass was provided by anglers who caught a few in each of the years 1936 to 1942. Further and more accurate evidence was sought by looking for bass nests, seining for young fish and gill-netting for adults.

The anglers' catch was difficult to verify in the absence of a compulsory creel census. Considering only those records which were officially verified, the catch ranged from 2 in 1936 to 12 in 1940. While this number is not large, it should be pointed out that angling was much restricted in these years. The area within one-half mile of the rearing grounds was always closed and for 4 years about three-quarters of the lake was closed to fishing.

The search for nests was carried on in 1936, 1939, 1941 and 1942.

No nests with eggs were found in Waskesiu or in the Heart Lakes although areas cleared by fish and presumably by bass, were found on several occasions in both lakes. Since fry were later collected in the Heart Lakes where no nests could be found, it is not surprising that no nests were found in Waskesiu Lake which has a shore length of 47 miles.

Seining in the hope of collecting fry or yearling bass in Waskesiu was also unsuccessful but in the Heart Lakes bass fry were taken on July 5, 1941 and again on July 16, 1942. Both these collections were made before any fry had been transferred from the rearing ponds at Waskesiu and thus they provide proof of the natural spawning of adult bass placed in the lake in previous years.

Extensive gill-netting was carried on between June 25 and September 14, 1942, in an attempt to assess the bass population of Waskesiu Lake. The nets used were in gangs of 150 yards comprising 25 yards of 1½-, 2-, 3-, 4-, 5-, and 5½-inch stretched mesh. A summary of the fish caught appears in Table 3, with comparative data from earlier netting in the years 1928 to 1934. Eight bass, making up 0.5 per cent of the total catch, were taken in the 20 settings. It is quite possible that these were individuals which had been released as mature fish. Seven settings in the Heart Lakes from July to September, 1942, took a total of 246 fish of which two (0.8 per cent) were smallmouth bass.

In both lakes the bass taken in nets and by angling were of large size. Those taken in the gill nets ranged from 12 to 16¼ inches total length, and weighed from 18 ounces to 2½ pounds. The absence of any smaller fish, which could be 1, 2 or 3 years old, suggests that the survival rate of fry released in the lake has been very low.

A comparison of the composition of the 1942 gill-net catches with those of the earlier years as indicated in Table 3, suggests important changes in the fish population. The decrease in the numbers of pike, ***Esox lucius,*** in the years 1928 to 1934, is the result of excessive trolling for that species in the years after the establishment of the park as recorded by the author, (Rawson, 1932). By 1934 the pike population was severely depleted and anglers experienced difficulty in making even small catches. The reduction in numbers of pike seems to have made possible a great increase in the pickerel, ***Stizostedion vitreum,*** from about 5 per cent of the gill-net catch in the earlier years, to 45 per cent in 1942. As a result large numbers of pickerel were taken by anglers in 1941 and 1942 although very few were caught in the earlier period. The closure of three-quarters of the lake in the years 1936 to 1939 allowed the pike to recover some of their numbers so the catch in 1942 was almost three times that of 1934. While these changes may have little direct bearing on the introduction of bass they are of great importance in the understanding and management of the game fish population. The data in Table 3 also suggest the intensity of the population pressure among the native species with which the bass must compete.

TABLE 3.—*The composition of gill-net catches in Waskesiu Lake from 1928 to 1942*

Item	1928-29-30		1932-33		1934		1942	
	Numbers	Percentage	Numbers	Percentage	Numbers	Percentage	Numbers	Percentage
Ciscoes (*Leucichthys* spp.)	1,053	40.7	336	28.2	636	30.7	131	8.0
Yellow Perch (*Perca flavescens*)	639	24.6	430	36.0	845	40.8	139	8.5
Common Sucker (*Catostomus commersonii*)	395	15.2	160	13.4	266	12.8	436	26.7
Pickerel (*Stizostedion vitreum*)	106	3.4	72	6.0	110	5.3	741	45.3
Whitefish (*Coregonus clupeaformis*)	136	4.2	56	4.7	130	6.3	33	2.0
Northern Pike (*Esox lucius*)	215	8.3	58	4.9	50	2.4	125	7.7
Northern Sucker (*Catostomus catostomus*)	39	1.5	46	3.9	32	1.5	18	1.1
Ling (*Lota maculosa*)	7	0.3	34	2.8	7	0.3	0.4	0.2
Smallmouth bass (*Micropterus dolomieu*)	....	....	....	....	....	....	8	0.5
Total numbers caught	2,490	....	1,192	....	2,076	....	1,635	....
Average number per setting	24	....	20	....	33	....	20	....
Number of net settings	108	....	60	....	63	....	81	....

Returning to our estimate of the success of smallmouth bass stocking it can be said that the results of gill netting and the anglers catches indicate a moderate survival of bass in Waskesiu and Heart Lakes. Bass made up 0.5 and 0.8 per cent respectively of the gill-net catches in Waskesiu and the Heart Lakes. If they are present in this proportion in the populations of these lakes they would seem to have been given a reasonable opportunity to establish themselves. The failure to discover natural spawning or to capture any young bass in Waskesiu make the prospects in that lake much less hopeful than in the Heart Lakes where naturally spawned fry were collected.

The absence of evidence that the 260,000 fry planted in these lakes have survived makes us consider the possible reasons for this poor showing. It was indicated above that the planting amounted to only two to four fry per acre which is definitely a light planting. Moreover, most of these fry were planted soon after they had risen from the nest and were thus deprived of the care of the guardian male bass. These factors and the heavy population of pike, pickerel and perch would tend to increase the mortality of the fry. It is hoped that these factors have only delayed and not prevented the establishment of bass in the lakes.

The success of natural spawning in the Heart Lakes may be correlated with the fact that they are smaller, shallower and therefore more readily warmed than Waskesiu. While suitable temperatures were observed during the preliminary observations in the bay at Waskesiu Narrows, it is possible that this was somewhat misleading in that much of the lake fails to maintain temperatures high enough for spawning in certain years. If the smallmouth bass continue to spawn and thrive in the Heart Lakes there are many other lakes in this region of similar size and depth, which should be suitable for bass. The results would suggest that it might have been wiser to confine the early plantings to the Heart Lakes, and to begin the transfer to Waskesiu only after success was in sight. This, of course, would have delayed the stocking of Waskesiu in which the improvement of angling was considered urgent.

Conclusions

The experimental introduction of smallmouth bass into Waskesiu and Heart Lakes of the Prince Albert National Park has been only moderately successful. The results of gill netting and angling show that the adult bass planted in the lakes have survived in fair numbers. We have, however, no evidence that fry reared in the lake are surviving to maturity. Natural spawning has been demonstrated in the Heart Lakes but not in Waskesiu.

The use of rearing enclosures, screened off in protected bays, has given satisfactory results. The method is inexpensive and provides excellent opportunities for control and observation of the breeding stock. It is considered desirable that rearing enclosures should be

supplemented by feeding enclosures in order to avoid having to plant the fry at an early stage. Crowding in the enclosures caused inefficiency in the production of fry.

Temperature changes were the most critical of the factors affecting success in rearing. In two years, 1936 and 1941, favorable temperature conditions made possible the rearing of large numbers of fry. In 1939 and 1942 a decline in temperature after the beginning of spawning resulted in considerable losses of eggs and fry. A rising temperature in the vicinity of 60° F. was found to initiate spawning and continued temperatures of not less than 65° were needed for best results in rearing.

Some of the lakes of the Prince Albert Park region appear to be suitable for bass. The larger and deeper lakes are probably marginal because of their lower temperatures but there are many shallow lakes which may prove to be good bass waters.

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COLUMNARIS AS A DISEASE OF COLD-WATER FISHES

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ABSTRACT

A natural outbreak of columnaris disease among wild adult and hatchery-reared fingerling salmon in the State of Washington is described. The disease is identified by the recovery of the causative organism, *Bacillus columnaris* Davis, which may be readily identified by its characteristic action in forming columns on the surfaces of infected material held in a water mount on a microscope slide. The gross lesions vary in appearance according to the particular organ affected but are formed, essentially, by the progressive necrosis and disintegration of the tissues. The tissues primarily affected are skin, body musculature, and the gills. Cultivation of the causative organism in tryptone solutions is recorded. Controlled, laboratory-induced infections indicate that among the cold-water fishes, columnaris disease is of little consequence to fingerlings at water temperatures below 55° F., but becomes highly pathogenic at temperatures in excess of 70° F. Between these temperature thresholds, the degree and severity of the infection is markedly influenced by factors adverse to the host. No effective control measures have been found.

Davis (1922) described a disease that had appeared among warm-water fishes of the Mississippi Valley. The disease was bacterial in origin and was called "columnaris" after the name *Bacillus columnaris* that he assigned to the causative organism.

Davis found natural infections of this disease among approximately 16 species of warm-water fishes in the general vicinity of Fairport, Iowa. Later, he found the disease among 2 additional species of warm-water fishes from the St. Lawrence River. Although his experiments were prematurely terminated, Davis succeeded in transmitting the disease from warm-water fishes to a single fingerling trout in the laboratory, thus establishing the fact that columnaris disease could attack cold-water fishes as well.

Columnaris disease has received little, if any, attention since Davis' investigations in 1918-19. To the writers' knowledge, the disease has not again been mentioned in the literature. Few fish pathologists seem aware of its existence in spite of Davis' warning that there is little reason to doubt that under favorable conditions columnaris disease may occur in nearly all species of fresh-water fishes.

During the summer of 1942, columnaris disease appeared as a natural outbreak among a Quinault strain of blueback salmon fingerlings, *Oncorhynchus nerka* (Walbaum), being reared at the Fish and Wildlife Service hatchery at Leavenworth, Washington. The disease rapidly attained epidemic proportions among these fish and was subjected to considerable study. The investigations are still being prosecuted but sufficient progress has been made to warrant publication of the

findings to date. It is hoped that their release may stimulate further interest in columnaris disease among fish pathologists generally and lead to a better understanding of the occurrence and nature of the disease.

The Quinault strain of blueback salmon was the only fingerling stock seriously affected during the 1942 outbreak at the Leavenworth hatchery. Scattered infections of columnaris disease were found among native (Columbia River) blueback in adjoining troughs, but the infection failed to become widespread. The same situation prevailed among the fingerlings of chinook salmon and steelhead trout and, to a lesser extent, among the silver salmon. Of particular interest was the recovery of the causative organism from well-developed lesions on wild adult chinook and blueback salmon, steelhead trout, squawfish, whitefish, chubs, and suckers taken from the Columbia River near Wenatchee, Washington. Apparently *B. columnaris* is established in the Columbia River—a fact that may prove of significance to the fishery resources of that important source of food and recreation.

The positive diagnosis of columnaris disease rests upon the recovery of the causative organism. Although Davis originally named the organism *Bacillus columnaris*, it appears quite certain that it does not belong in the present concept of the genus *Bacillus*. Irrespective of the uncertainties surrounding its taxonomic status, the organism is sufficiently characteristic in its appearance and actions to engender little doubt in its recognition. It is a rod-shaped, Gram-negative organism measuring about 0.5 microns in diameter and 4 microns in length, appearing in filamentous chains. *B. columnaris* appears to possess a flexible cell wall and is usually found attached to the underlying tissues of the host at one end from which the organism undulates in the relatively long waves described by Davis. The most characteristic action of *B. columnaris* is its habit of gathering in long columns while on the microscope slide. The mechanics of this striking action are not clear. If a bit of infected tissue is held in a water mount under the microscope, a series of regularly spaced columns of the bacteria form within a period of 10 to 20 minutes. The columns progressively elongate, each appearing as a miniature "hay-stack" composed of a swarming mass of waving organisms. The columns have been observed to extend a greater distance from the sub-stratum than was pictured by Davis and to form columns roughly four times longer than wide, terminating in an enlarged globular mass of organisms. Eventually the entire column disintegrates into a myriad of individual organisms that tend to collect upon the lower surface of the cover slip. Perhaps the reason why columnaris disease has not been more generally recognized lies in the fact that the typical column formation does not develop in the living fish. Furthermore, a period of minutes is required for column formation—usually a longer period than is devoted to routine examinations.

The lesions produced by *B. columnaris* on the cold-water fishes are

essentially a progressive necrosis and subsequent disintegration of the tissues varying in gross appearance according to the particular organ affected. The superficial gross lesions appear to develop about points of traumatic injury or in the gill tissues. Lesions are common in the soft inter-ray tissues of the fins, particularly the caudal, and develop as a progressive disintegration of the fin eventually reaching and invading the body musculature. This type of fin lesion forms the typical "tail rot" frequently observed among hatchery trout and salmon although, heretofore, not correlated with columnaris disease. Infections are likewise common about the anterior part of the snout—possibly developing from superficial ulceration of the epithelium resulting from contact with the trough screens. Gross gill lesions appear as dry infarcts, often unilateral in distribution, and involving part—or all— of the gill tissues. A bright hemorrhagic area at the anterior confluence of the branchiostegal rays often accompanies infections of the gills. The gill tissues react to columnaris disease in a manner typical of a continuous irritation producing a pronounced epithelial hyperplasia of the lamellae and gill rakers. Eventually the epithelial layer sloughs, followed by the disintegration of the lamellae and finally of the central cartilaginous structures of the filaments.

No gross internal lesions have been observed beyond the necrosis and tissue disintegration in cases wherein the infection has progressed inward from an established fin lesion.

The gross lesions of columnaris disease closely resemble those ascribed to "tail-rot," fin rot, and ulcer disease, although the uncertain aetiology and lack of specific control measures for the latter disease render any confusion of little practical consequence. The large number of characteristic bacteria—quite unlike those found in any other known disease of fishes—serves to accurately identify columnaris disease. Likewise, the earlier stages of gill infections by columnaris disease are indistinguishable from the tissue lesions formed by bacterial gill disease although, again, the characteristic movements of the columnaris organism proves an easy criterion for distinguishing between the two diseases.

The course of columnaris disease among salmonid fishes is, as was noted by Davis with reference to warm-water fishes, markedly influenced by water temperature. In controlled experiments, the effect of water temperature upon laboratory-induced infections of *B. columnaris* among 3-inch blueback-salmon fingerlings proved very apparent. As an example, 50 fish were placed in each of 6 troughs. The water supplies to the troughs were equipped with thermostatically-controlled valves maintaining a constant temperature of the inflowing water. Eight days later, the skin on the left side of 25 fish in each trough was scraped to the corium over an area of approximately 1 square centimeter. All of the fish were then herded into the upper end of the troughs by means of sliding screens, the water supply to each trough stopped, and 100 cc. of a 5-day tryptone culture of *B. columnaris*

added to four of the troughs, leaving one uninfected control trough at the maximum and minimum temperatures. The water flow was resumed after a period of 30 minutes. Each dead fish subsequently removed from the troughs was carefully examined for *B. columnaris*. A resume of the results obtained from this infection experiment appears in Table 1.

TABLE 1.—*Mortalities among 3-inch blueback salmon fingerlings during a 38-day period following exposure to* B. columnaris *infection*

Temperature °F.	Infection	Injury	Percentage mortality	Recovery of *B. columnaris*
70	Uninfected controls	Injured	0	....
		Uninjured	12	Negative in all cases
	Infected	Injured	100[1]	Positive in all cases
65	Infected	Uninjured	100[2]	do.
		Injured	24	do.
		Uninjured	12	do.
60	Infected	Injured	60	do.
		Uninjured	32	do.
50[3]	Infected	Injured	0	....
		Uninjured	0	....
	Uninfected controls	Injured	0	....
		Uninjured	0	....

[1]All fish dead within 48 hours after exposure.
[2]All fish dead within 72 hours after exposure.
[3]During early part of experiment, water temperatures were set at 50° F. but slowly increased to a maximum of 57° F. at the close of the experiment due to lack of precooled water supply.

These, and other, data acquired from controlled infection experiments indicate that among the cold-water fishes, columnaris disease is of little consequence to fingerlings at temperatures below 55° F. but that it becomes extremely virulent at temperatures in excess of 70° F. Presumably, between these temperature thresholds, *B. columnaris* progresses from a relatively non-pathogenic organism to a highly pathogenic one, the degree and severity of the infection being markedly influenced by factors adverse to the host, such as mechanical injuries.

Successful attempts were made to cultivate *B. columnaris* on artificial media. Although fish-tissue broth, Difco nutrient broth, Difco nutrient agar, and peptone solutions yielded inconsistent and generally poor results, the organism grew readily and luxuriantly in a 0.5 per cent aqueous solution of Bacto-tryptone adjusted to pH 7.2. Optimum growth was obtained at 85° F. *B. columnaris* on agar media proved pleomorphic in that only small coccoid granules, resembling microcysts, could be found after incubation of 7 to 10 days. No change in form was found in liquid media cultures.

Some evidence was obtained indicating that *B. columnaris* may be carried in the blood stream despite the fact that gross foci of infection could not be found among the internal organs. Twenty-five fingerlings exhibiting external lesions of columnaris disease were immersed in 70 per cent alcohol for 2 minutes and flamed to the point of thoroughly cooking the surface tissues. The specimens were then opened

aseptically and cultures from the heart, liver, spleen, and kidney were planted in 0.5 per cent tryptone broth. Twenty-three of the 25 kidney cultures yielded a pure growth of *B. columnaris,* as did 18 of the heart-cultures, 13 of the liver cultures, and 7 of the spleen cultures.

Bits of infected tissues were flooded on a microscope slide with various concentrations of azochloramid, copper sulphate, crystal violet, metaphen, methylene blue, neutral acriflavine, mercurochrome-220, chlorazene, and Aerosol-OT in the hope of finding a disinfectant to control the disease. None of these compounds indicated any promise in that concentrations sufficiently strong to affect *B. columnaris* likewise proved toxic to the fish in comparable periods of exposure. Infected fish were subjected to prolonged treatments with potassium permanganate 1:400,000, formalin 1:4,000, and acetic acid 1:10,000, and potassium permanganate flushes, with no beneficial results.

At the present time the only effective therapeutic measure against columnaris disease lies in the transfer of infected stock to water temperatures below 55° F. At hatcheries where columnaris disease is known to exist, the handling of stock with the inevitable attending mechanical injuries should be avoided—or reduced to an absolute minimum—during periods when the water temperature exceeds 55° F.

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A COMPARISON OF THE HOOP-NET CATCHES IN SEVERAL FISH HABITATS OF WHEELER RESERVOIR[1]

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ABSTRACT

Hoop nets were fished in all four major habitats in Wheeler Reservoir, a T.V.A. main-stream impoundment, during a six-months' period in 1941. Long-nose gar, mooneye, skipjack, mud catfish, black bullhead, white bass, sauger, and crappie were best represented in the catch from the fast tailwater; drum were taken in greatest numbers in the upper "third," which had retained many of the characteristics of the original river; rough-fish species were most commonly caught in the middle section with its extensive shallow backwaters; and Kentucky bass were best represented in the lower "third" where the water is less turbid than in other portions of the reservoir.

Main-stream reservoirs of the Tennessee Valley Authority are divided into four more or less distinct areas: (1) A fast tailwater at the head of the reservoir, (2) an upper section where the water is confined to the original channel, (3) a middle section where the water overflows portions of the original river bank and forms large shallow backwater areas to either side of the river channel, and (4) a lower "third" where the water is deep and extends to the steeper slopes bordering the old river basin.

The four areas differ with respect to depth, flow, and turbidity, and are affected differently by water-level fluctuation. Depth is the least in the tailwater, and is greatest in the lower section. The flow is very rapid in the tailwater, is still perceptible in the middle "third," and is almost absent in the lower area. As might be expected, the decrease in flow permits the settling out of suspended matter, hence, the water in the lower area is normally less turbid than that in the middle or upper area. The turbidity may be affected by tributaries or by the abundance of rough fish in the backwaters and therefore is not entirely dependent on the rate of flow. Fluctuations in level influence the middle area much more than the other portions of the reservoir because in the middle area a drop in level of a very few feet may expose many acres of bottom in the shallow, but extensive, backwaters.

Due to the extensive difference in environmental conditions, fish in a main-stream reservoir have available a variety of habitats, ranging from a fast-flowing river at the upper end of the reservoir to a condition closely resembling that found in normal lakes in the lower section.

As a preliminary attempt to determine the relative abundance of fish of several species in the four major areas, hoop nets were set in various localities in Wheeler Reservoir, Alabama, the sixth in a series of nine main-stream reservoirs which impound the Tennessee River from its

[1]Published by permission of the Tennessee Valley Authority.

source near Knoxville, Tennessee, to a point near its mouth, in the vicinity of Paducah, Kentucky. It is well known that hoop nets are highly selective for different species of fish. For an individual species, however, the use of identical hoop nets in several areas should provide valid information for a comparison of the relative abundance of fish of that species in the several areas, even though data on the total abundance cannot be obtained.

The hoop nets in Wheeler Reservoir were fished during a 6-months period beginning in April 1941. The number of individual overnight sets, averaging about 22 hours per set, were: Guntersville Dam tailwater, 40; Upper Wheeler Area, 24; Middle Wheeler Area, 145; and Lower Wheeler Area, 71. The nets used in this study were described by Smith and Miller (1943). Netting activities were invariably confined to one area at a time, and the six nets used simultaneously usually were not moved for a period of about 1 week, although the fish were removed from the nets at least once each day.

Assistance in the netting was provided by Charles G. Smith, Loyd Stewart, I. E. Qualls, Jesse Frederick, and A. R. Britton, Jr., all members of the Biological Readjustment Division staff. Dr. A. H. Wiebe, Chief of the division, and Dr. C. M. Tarzwell offered many helpful suggestions during the course of the inquiry.

The catch was recorded on a basis of 100 individual net sets in order to permit direct comparison (Table 1). The number of fish caught per net was greatest in the tailwater and least in the upper "third" of the reservoir.

Longnose gar, mooneye, skipjack, mud catfish, black bullheads, white bass, sauger, and both species of crappie were taken in greatest numbers in the fast tailwater. Most species of rough fish were best represented in the catches from the middle section, as were also the channel catfish, blue catfish, and brown bullhead.

One species, the drum, was much better represented in the upper section than in the other three areas, presumably because this upper portion of the reservoir most nearly retains the characteristics of the original river, retaining the molluscan fauna which supposedly constitutes the major food of the drum.

The Kentucky bass, and several species of sunfish, were best represented in the catch from the lower portion of the reservoirs. Bluegills were reasonably abundant in all areas.

The two species of crappie were both present in all four areas, and collectively they represented two-thirds or more of the catch from each section. Although both were best represented in the tailwater, the black crappie showed greatest preference for this area. The ratios of black crappie to white crappie in the four areas (from tailwater to lower "third") were: 7.7:1, 1.5:1, 1:1.8, and 1:2.3, respectively, indicating a distinct tendency for the white crappie to replace the black crappie in the lower parts of the reservoir.

This study does not take into account the seasonal variations in the

TABLE 1.—*Catch of fish per 100 hoop net sets in the four major habitats of Wheeler Reservoir, 1941*

	Species[1]	Guntersville[2] tailwater	Upper Wheeler	Middle Wheeler	Lower Wheeler
Coarse Fish:					
1	Shortnose gar	11	13	24	2
2	Longnose gar	22	4	4	1
3	Dogfish	....	....	1	....
4	Mooneye	12	....	1	....
5	Skipjack	9	....	1	2
6	Gizzard shad	32	16	66	38
7	Bigmouth buffalo	....	....	2	....
8	Black buffalo	....	....	6	....
9	Smallmouth buffalo	....	....	43	9
10	Quillback carpsucker	....	4	3	....
11	Spotted sucker	....	....	10	....
12	Silver mullet	....	....	1	1
13	Ohio redhorse	....	4	2	2
14	Carp	15	4	20	13
Food Fish:					
15	Channel catfish	....	....	6	....
16	Blue catfish	....	....	2	1
17	Mud catfish	44	13	11	11
18	Black bullhead	76	....	....	1
19	Brown bullhead	....	4	27	....
20	Yellow bullhead	....	....	5	....
21	Drum	8	75	8	4
Game Fish:					
22	Chain pickerel	....	....	3	....
23	White bass	139	....	38	1
24	Yellow bass	....	....	3	....
25	Sauger	12	....	1	....
26	Kentucky bass	21	4	1	31
27	Largemouth bass	....	....	4	....
28	Warmouth bass	3	4	2	4
Pan Fish:					
29	Green sunfish	....	....	1	4
30	Longeared sunfish	....	....	1	1
31	Bluegill	212	137	206	195
32	Redear sunfish	2	....	5	14
33	Rock bass	....	....	1	....
34	Black crappie	14,578	354	385	165
35	White crappie	1,891	241	693	422
	TOTAL	17,087	877	1,587	922

[1]Scientific names of species, numbers corresponding with numbers in Table 1: 1 *Lepisosteus productus*, 2 *Lepisosteus osseus*, 3 *Amia calva*, 4 *Hiodon tergisus*, 5 *Pomolobus chrysochloris*, 6 *Dorosoma cepedianum*, 7 *Megastomatobus cyprinella*, 8 *Ictiobus niger*, 9 *Ictiobus bubalus*, 10 *Carpiodes cyprinus*, 11 *Minytrema melanops*, 12 *Moxostoma anisurum*, 13 *Moxostoma breviceps*, 14 *Cyprinus carpio*, 15 *Ictalurus lacustris*, 16 *Ictalurus furcatus*, 17 *Pilodictis olivaris*, 18 *Ameiurus melas*, 19 *Ameiurus nebulosus*, 20 *Ameiurus natalis*, 21 *Aplodinotus grunniens*, 22 *Esox niger*, 23 *Lepibema chrysops*, 24 *Morone interrupta*, 25 *Stizostedion canadense*, 26 *Micropterus punctulatus*, 27 *Huro salmoides*, 28 *Chaenobryttus gulosus*, 29 *Lepomis cyanellus*, 30 *Lepomis megalotis*, 31 *Lepomis macrochirus*, 32 *Lepomis microlophus*, 33 *Ambloplites rupestris*, 34 *Pomoxis nigro-maculatus*, 35 *Pomoxis annularis*.

[2]Wheeler Reservoir extends from Wheeler Dam to Guntersville Dam. The Guntersville tailwater is therefore actually a part of Wheeler Reservoir.

relative abundance of fish of various species in the several habitats. It has been noted, for example, that migrations of fish to the tailwaters may be of sufficient magnitude to decidedly alter the composition of the fish population (Eschmeyer, 1943). White bass, largemouth bass, and sauger are known to periodically appear in large numbers in the tailwaters. Longnose gar, too, are very abundant in the tailwaters at times, and are poorly represented in these areas at other times. At certain times the distribution of fish of any species may, therefore, differ widely from that noted in Table 1. Because of the variety of fish habitats and the extensive movements of a number of species, fishing for any species in T.V.A. reservoirs may be expected to be more successful as the habits of that species become better known.

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A CASE OF OSSIFICATION OF THE SPINAL COLUMN IN FISHES

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ABSTRACT

A peculiar carp, (*Cyprinus carpio*), was caught in the upper Illinois river. The fish was 7 years old and had a total length of 9 inches as compared to 20 inches for a normal carp of like age. The last 8 thoracic and the 17 caudal vertebrae had been softened and squeezed together, and ossification and the formation of new bone had caused permanent fusion. The condition has been named *Spondylitis ossificans piscium* and bears a marked resemblance to *Arthritis deformans*.

Possible causes of the condition are discussed.

During the summer of 1935 the Illinois Natural History Survey was studying the fish population of Lake Senachwine, a bottom-land lake of about 5,000 acres near the town of Henry, on the Illinois River. In the course of the fishing operations a peculiar carp (*Cyprinus carpio*) was caught in the fyke nets. the fish was stocky and very deep, and the posterior half of the body was stiff. The tail movements appeared to originate in the thoracic region and the carp experienced considerable difficulty in swimming.

The carp was subjected to an autopsy in the laboratory, where the various organs of the body were examined for infection, and bacteriological cultures and smears were made. The cultures were all negative. The gall-bladder was dark green, very large, and tightly filled. Such a condition indicated that the fish had not eaten for a considerable period. Apparently the functions of the liver were not impaired, as was evidenced by the gall-bladder, although it was very pale and did not have the usual reddish-brown color characteristic of the liver of a healthy fish. An examination of the scales indicated that the fish was 7 years old; it weighed $2\frac{1}{2}$ pounds and had a total length of 9 inches. These figures are in marked contrast to the average weight and length of a normal 7-year-old carp (7 pounds; 18 to 20 inches). The cleaning of the skeleton according to routine methods revealed a deformity of the vertebral column (Figure 1). The first 9 thoracic vertebrae were normal and unaffected; the affected vertebrae consisted of the last 8 thoracic and the 17 caudal. These latter portions of the spine were shortened considerably. The vertebrae seem to have become softened and squeezed together and then by ossification and new bone formation to have become fused permanently in this shortened condition. Upon further examination it was found that the intervertebral cartilages were completely eroded and the joint spaces obliterated; furthermore, spicules of new bone could be seen at the edges of the joint. Examination of the X-ray photographs reveals three centers of heavy ossification; from their appearance these are

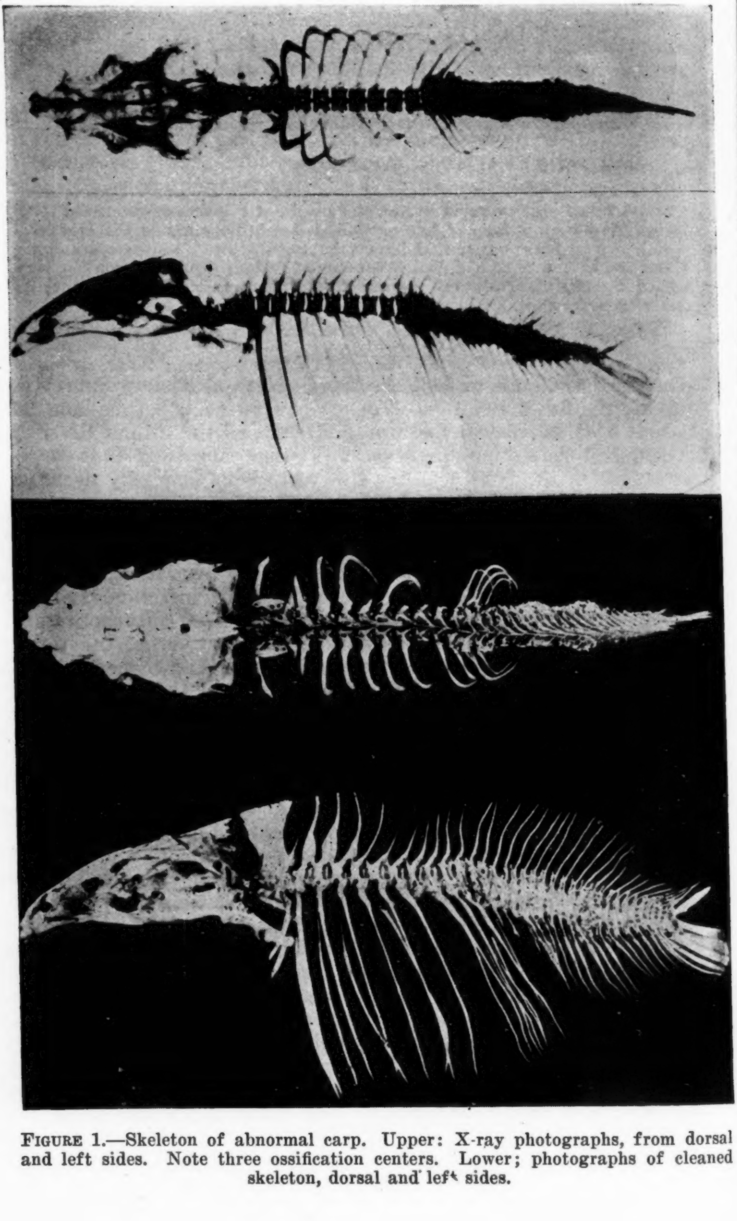

FIGURE 1.—Skeleton of abnormal carp. Upper: X-ray photographs, from dorsal and left sides. Note three ossification centers. Lower; photographs of cleaned skeleton, dorsal and left sides.

believed to be points at which the stiffened spine had been broken and then repaired by new bone formation. In the deformed fish the posterior zygapophyses are heavier than those found in the normal carp. Another important difference between this and the normal carp, of the same age, is the enlargement of the neural space to approximately twice normal size. The decrease in length is probably due to the normal tension of the lateral masses of muscle while the vertebrae were in a softened condition (MacBride, 1932).

The present case of spinal deformity has been tentatively named *Spondylitis ossificans piscium.* There is a striking resemblance between the deformity and *Arthritis deformans* as found in man, horses, cattle, and other animals (McCrae, 1906; Axhausen, 1912; Nichols and Richardson, 1909). According to Lovett (1922), the earliest change in the disease in man—softening of the cartilage—is not seen on the radiograph, but later, definite erosion takes place and narrowing and irregularity of the joint spaces become visible. The greatest amount of softening and erosion occurs at the periphery, and proliferation of bone and thickening of the synovial membrane follow immediately. X-ray examination at this stage reveals an irregularity and lipping of the edges of the bones, with a narrowing or complete obliteration of the joint space. This condition is quite similar to that found in the present carp.

According to Rosenow (1904) and Chapman (1920), the generally accepted point of view is that arthritis in man must be considered as a disease involving some dislocation in at least four systems of the body, namely, the endocrine, vascular, nervous, and gastro-intestinal, and is due to an unbalance of the normal physiological functions of these systems.

The deformad carp was caught in the polluted section of the upper Illinois River, and one may suppose that these abnormal living conditions would exert some influence upon one or more of the above-mentioned systems. Focal infection seems to be the most important of the several specific factors which can be regarded as actually initiating arthritis (Billings, 1913). The most important site for focal infection in the fishes is the gall-bladder. This organ may actually be the focus of true infection or it may share in the sluggishness of the gastro-intestinal tract, as has been observed upon several occasions. These conditions will very likely lower the general resistance and the gall-bladder would tend to become the center of an infection of a low-grade order. Our bacteriological observations were negative and, therefore, we are obliged to look elsewhere concerning the cause of the deformity. It is extremely unlikely that the condition is at all like the deformed or shortened spines found in cattle and believed to be due to a "short spine" lethal (Mohr and Wriedt, 1930).

As a result of this study the only conclusion to be made is that the present deformity in the carp is an arthritis and similar to the condition found in man and other animals. The deformity has been named

Spondylitis ossificans piscium. Although the exact cause is unknown, it is quite likely that the extreme difficulty which this fish undoubtedly encounters in securing food must exert considerable influence upon the gastro-intestinal system of the body.

Acknowledgments

I wish to acknowledge my indebtedness to Dr. Cesare Gianturco of the Carle Memorial Hospital, Urbana, Illinois, for his valuable advice during the progress of this work. I am further indebted to Dr. Gianturco for the X-ray plates appearing in this paper.

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STUDIES OF THE TOXICITY OF AMMUNITION PLANT WASTES TO FISHES

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ABSTRACT

A reported, but as yet unconfirmed, ill effect on fishes of wastes from a munition plant led to a study of the toxicity of these wastes to fishes. The red liquor from the manufacture of tri-nitro-toluene (T.N.T.) was suspected. The constituents of this waste include dissolved T.N.T. and toluene, both of which are very toxic. Many other compounds which may be very toxic are also present.

Certain minnows are similar in sensitivity to trout yolk sac and very young fry of the trout. The red liquor waste from T.N.T. manufacture was found to kill these fishes when the dilution of an average sample was 600 times or less. A safe dilution is probably 1,000 times during the cooler months.

A rise in temperature which occurs in streams at the time of low water increases toxicity and requires greater dilution when it is actually least.

The pollution of streams with wastes from ammunition factories is enormously increased during a war. This study was undertaken because of the alleged damage to fishes at a point near a munitions plant. While the damage has not been fully substantiated, there is no doubt but that the wastes investigated are capable of doing widespread damage whenever dilution is insufficient. There has been relatively little study of the effect of ammunition plant wastes on fishes. Some unpublished results have been provided through the courtesy of the Illinois State Sanitary Water Board, but work remained to be done on young stages of fishes and adult species of similar sensitivity as shown by the studies of Goodnight (1942).

The material used in manufacturing T.N.T. are toluene, nitric acid, sulphuric acid, and water. Toluene is nitrated in three steps, but no wastes enter the streams from these processes because the acid is recovered and removed. At a certain point, the product is subjected to a hot-water wash followed by a cold-water wash, and these waters make up the acid wastes resulting from T.N.T. manufacture. This acid wash water is yellow in color. Following the cold-water wash, the T.N.T. is treated with sodium sulphite and sodium carbonate. Sodium sulphite tends to dissolve the products of nitration, and produces a red liquor. The products of nitration go into solution in the alkaline state. The constituents of the red liquor are reported to be organic substances: 6.4 to 7 pounds per 100 pounds of T.N.T. and 6 pounds of sodium salts per 100 pounds of T.N.T. Organic wastes from T.N.T. manufacture make up 95 per cent of the red liquor. They contain, in addition to by-products, small amounts of T.N.T. as a precipitate, and traces in solution. F. W. Mohlman, director of laboratories of the Sanitary

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District of Chicago, has made a study of war-time wastes and has stated the results with T.N.T. as follows:

"The red wastes are alkaline, have a very high color, even in 1:50 dilution, and contain nearly 6 per cent total solids, of which about 45 per cent is volatile. The composite waters are quite acid, contain about 3.5 per cent solids and have a high color even in 1:500 dilution.

"It is essential to know the volume and analyses of wastes per batch in order to relate the problem of disposal to the receiving stream. Numerous analyses of 'T.N.T. wastes' have been made, but the results of analyses depend entirely upon the production and the amount of cooling water mixed with the actual organic wastes, and unless the results are related to the production at the time the samples were collected, computations of necessary dilution, or experiments on the biological effect of the waste on fish, on taste, on color, etc., are unrelated to the output of the plant.

"The wastes have no odor and no appreciable B.O.D. (Capacity to take up Oxygen). They are very stable and resistant to biological oxidation. All of the available methods of sewage or waste treatment are ineffective for removal of organic matter and color, except, as was found in laboratory tests when the problem was approached in March, 1942, the use of chlorine for decolorization. It was found that the color could be reduced from 600 to 75 p.p.m. by application of 1,400 p.p.m. chlorine, equal to 1.9 tons of chlorine per day for the plant under consideration.

"Further studies, however, showed that by taking account of the stream flow in various rivers, providing for storage of wastes direct from the wash house in large holding basins at times of minimum river flow, and discharge of the stored wastes at later periods of increased river flow, no treatment of wastes would be necessary."

Material Used

The ammunition plant wastes used throughout this study were collected from the Kankakee Ordnance Works by using an automatic sampler which takes approximately 20 samples per minute, the time interval being controlled by the velocity of flow in the channel from which the samples are taken. The sampler is one constructed by the United States Public Health Service, and is a sample wheel which collects a uniform volume. The sample used in this study represented the results of a 24-hour collection of the water by the automatic sampler. The first sample was obtained through the cooperation of the Illinois State Sanitary Water Board. The arrangements were made by C. W. Klassen, and 5-gallon samples of each mixed waste (from tetryl area) and red liquor were secured by A. Paul Troemper, Senior Sanitary Engineer.

The following analysis of the samples was made by the Sanitary Water Board Laboratory:

Item	*Composite red liquor waste*	*Tetryl area waste*
Suspended solids, estimated	25	15
Residue on evaporation:		
Total	2,380	1,370
Volatile	1,080	520
Sulphate	250	320
Hardness, p.p.m.	275	290
Nitrite nitrogen	1.4	0.031
Nitrate nitrogen	47	.05
Acidity	260	560

Analysis by the University of Illinois Applied Chemistry Testing Laboratory and the Illinois State Water Survey showed the presence of small but undetermined amounts of toluene.

A second sample of the T.N.T. red liquor waste was secured in November, 1942, through the courtesy of Major Emil F. Werley. No analysis of this was made, but a comparison of color showed that it was more concentrated. The results with fishes indicated a much greater concentration.

Fishes Studied

The following species of fish were studied:

Black fin minnow, *Lythrurus umbratilis* (Gir.)
Bunt nose minnow, *Hyborhynchus notatus* (Raf.)
Steel color minnow, *Cyprinella whippli* (Gir.)
Bluegill sunfish, *Helioperca incisor* (C. & V.)
Top minnow, *Gambusia affinis*
Lake trout, *Cristivomer n. namaycush* (Wal.)
Silvermouth minnow, *Ericymba buccata* Cope
Carp, *Cyprinus carpio* (Linn.)
Black bullhead, *Ameiurus melas* (Raf.)
Redhorse sucker, *Moxostoma aureolum* (Le S.)
Warmouth bass, *Chaenobryttus gulosus* (C. & V.)
Green sunfish, *Lepomis cyanellus* Raf.

The young stages of fishes are far more sensitive than the adults. The fishes used most generally in this type of work at the University of Illinois Zoological Laboratories are the young of lake trout and certain minnows of similar sensitivity which have been tried out with several kinds of water and other substances.

Methods of Study

The laboratory in which the work was done is supplied with hard water which comes from deep wells. It is chlorinated and filtered. The chlorine is removed by activated-carbon filters, following which the water is aerated. This supply has been proved uniform and usually satisfactory for use with fishes.

In these experiments, various concentrations of T.N.T. red liquor waste and mixed wastes (combined waste from tetryl area) were diluted with laboratory water. Tests were conducted in open battery jars in a constant temperature bath (Shelford, 1918). Various temperatures ranging from 15 to 25° C. were used to determine the effects of an increase in temperature on the survival time. Two liters of solution and 3 to 5 fish were used per battery jar. With large species of carp and black bullhead, a small aquarium, 16 by 8 by 10 inches, was placed in the constant temperature bath. Ten liters of solution and 2 fish were used with compressed air for aeration.

For three species of minnows and the lake trout young stages, observations were first made at 20, 12½, 10, 7½, 5, and 2½ per cent of T.N.T. red waste water and tetryl wastes. The second sample of T.N.T. red waste water was tested at lower concentrations: 2, 1, 0.5, 0.25 per cent on three species of minnows (see Table 1).

TABLE 1.—*Time to death, in minutes, of fishes exposed to the low and minimal lethal concentrations of munitions wastes and some of their constituents.*

[Temperature, 17 to 18° C. Weight in grams or length follows name of fish.]

	Red Liquor Wastes						Sat. Sol. TNT		Toluene		Tetryl Wastes
	First Sample		Second Sample[1]				Lab Water	Dis. Water			
Item	(1) 5% pH 7.2	(2) 20% pH 7.2	(3) 2% pH 8.0	(4) 1% pH 7.9	(5) 0.5% pH 7.7	(6) 0.25% pH 7.6	(7) 20% pH 7.3	(8) 20% pH 7.1	(9) 50p.p.m.	(10) 90p.p.m.	(11) 40%
Blunt-nose minnow (3 gm.)	133	37	255	L[2]	L	L	87	62	....	....	31
Black-fin minnow (2 gm.)	142	45	....	....	....	....	....	....	....	....	25
Silvermouth minnow (2 gm.)	130	40	120	2,680	L	L	110	102	....	....	41
Lake trout fry (15 days old)	168	40	130	230	400	L	....	....	258	390	....
Steel-colored minnow (2.0 gm.)	160	50	....	....	....	....	67	42	....	....	....
Bluegill sunfish (2.8 gm.)	402	106	....	....	....	....	73	57	....	....	....
Top minnow (1.5 gm.)	498	119	....	....	....	....	....	....	....	....	....
Green sunfish (small)	....	....	....	....	....	....	....	....	....	47	....
Red Horse (5½ inches)	....	97	....	....	....	....	....	....	....	....	....
Warmouth bass (small)	....	....	....	....	....	....	....	....	264	....	....
Black bullhead (11-13 inches)	....	254	....	....	....	....	556	370	....	....	....
Carp (11-13 inches)	....	126	....	....	....	....	455	300	....	....	....

[1]Second sample results were obtained by C. J. Goodnight and M. L. Goodnight as a check on the work of the author.
[2]L = Lethal.

Later larger fishes, two game species and two rough food fishes, were tested, together with two species of sucker and a few others (Table 1).

The thousand or more fish used in these tests were kept in aquaria supplied with the laboratory water. They were used only after several days in the laboratory. Controls consisted of the same number of fish as in the test jars, placed in water from the same source, but containing none of the red liquor or mixed wastes. The temperature was controlled by water surrounding the jars. This last mentioned water was kept running throughout the tests.

The second series of tests with the red liquor wastes were undertaken in the winter and spring of 1942-1943 by Goodnight and Goodnight in the same manner. A second sample collected in the same place was used. This sample was more toxic than the first due to some difference in the concentration of the constituents. The greatest differences in the time until death were observed in the low concentrations where the second sample appeared to be about 10 times as toxic as the first.

Since toluene is present in the waste, experiments were conducted with different concentrations of commercial toluene. The toxicity of the red liquor is probably in part due to the toluene contained in it. The results are in columns 9 and 10 of Table 1.

A saturate solution of T.N.T. was made up in both distilled and laboratory water. Experiments with both were undertaken. The results are shown in columns 7 and 8.

Results

In the first sample of red waste, the fish became intoxicated in 1 minute in 20 per cent solution to no signs of effect in 2½ per cent. The fish come to the surface, gasping for air, finally lose their equilibrium, sink to the bottom, and breathe rapidly. In less concentrated solutions above a tolerated concentration, the reaction of the fish is less violent, but results fatally. Post-mortem examination showed no significant lesions.

Mohlman (1943) reported that the concentration of the average sample of the red waste contained 35,000 p.p.m. of solids. The sample referred to as the first sample had only 2,380 p.p.m. of solids, while from its toxicity the second sample was estimated at 23,000 p.p.m.

To be harmless to fishes, this had to be diluted 1 to 400 as compared with 1 to 40 in the case of the first sample. This is equal to 1 to 600 or 1 to 800 for Mohlman's average sample, and the waste would be harmless a short distance from source in a rather large stream at average flow. The same substance could be very harmful at low water. Mohlman recommends a dilution of 1 to 10,000 for water for human consumption. This dilution nearly eliminates the undesirable red color.

Since the wastes are a mixture, it is desirable to know the effect of

different constituents taken separately. Accordingly, tests of commercial toluene and T.N.T. were used in a few experiments (Table 1, columns 7, 8, and 9). A 20 per cent dilution of water saturated with T.N.T. was somewhat less toxic than a 5 per cent dilution of the first sample of the red liquor waste. A 50 p.p.m. of toluene was less toxic. The tetryl wastes were relatively less toxic than the red liquor waste (Table 1, column 11).

When streams are lowest in the eastern portion of the United States, air and water temperatures are at their highest. Accordingly the effect of higher temperatures was tested. A rise in temperature of 5° C. (above 18° C.) decreased the survival time by an average of 21 per cent in a 20 per cent solution of T.N.T. red liquor waste. An increase of 7° above 18° C. in a 12½ per cent solution decreased survival time 32 per cent. A 7° C. increase in temperature in a 7½ per cent solution caused a reduction in survival time of 34 per cent. Furthermore, the effect of a rise of temperature increased with the dilution of the waste. In these experiments, 3 minnows were used; similar experiments were undertaken with the blue gill and all results showed the same trend.

Discussion

Results of several preliminary studies regarding which information was on file with the Illinois State Sanitary Water Board were made available by Mr. Klassen. The reports did not show the identification of species or size and weight of individuals used. A comparison of the time to death of the various species as shown in Table 1, column 2, indicated the wide discrepancy between species. The top minnow, smallest in size of the entire group, was almost 3 times as resistant as the largest silver mouth minnow or trout fry, while the black bullhead is 2 times as resistant as the carp of the same length. The decrease in time to death has been shown to be directly proportional to the increase in concentration of poisonous substances (Powers, 1917). This fact holds, however, only for concentrations in which fish die within a few hours or less. The deaths come proportionally more quickly in the most dilute solutions.

The work to date indicates that in order to make really definite determinations of the proper disposal of these wastes, very many conditions must be taken into account, including the rate of flow and the temperature of the stream receiving the waste. These conditions vary throughout the year. The capacity of the plant and the degree of dilution of the waste must also be known with respect to stream conditions. The test of toxicity with fishes and other biological material must be made with due reference to factory and stream conditions. The fishes used must be known as to size and species. However, concerning this point, only the direct killing of fishes has been considered.

Long-time effects on reproduction and growth have not been considered. The first type of work feasible to undertake is studies of the

rate of growth of young fishes when in polluted and normal water. As yet, such studies have not been undertaken.

Summary

1. All sensitive and young stages of fish died in concentrations of T.N.T. red-liquor waste greater than approximately 1 to 600 dilution of average samples as described by Mohlman (17° to 18° C.).

2. Increases in temperature of a magnitude which may occur in the low water period of mid-summer, decrease the survival time in T.N.T. waste from an average of 21 per cent in higher concentrations to an average of 34 per cent for the lower (7½ per cent).

3. Tetral area mixed wastes are fatal to silver mouth minnows, blackfin minnows, and blunt-nosed minnows in 40 per cent and 50 per cent concentrations of the sample studied.

4. Smaller specimens died sooner than the larger individuals, but the smaller specimens showed greater resistance per unit weight.

5. The factors to be taken into account in evaluating the effects of these wastes are numerous. All investigations to date are very imperfect. Thus a large margin of safety is needed in the dilutions.

Acknowledgments

The following persons have made materials and advice available for this report: Dr. V. E. Shelford, in whose laboratory the work was undertaken; Mr. C. W. Klassen, Chief Sanitary Engineer from the Department of Public Health, Springfield, Illinois; Dr. D. H. Thompson, Natural History Survey Division for collecting large species of carp and black bullhead; and the chemists who were responsible for the various analyses reported. The writer also wishes to express his gratitude to the Graduate School Research Board of the University of Illinois for the funds granted for the analysis of the T.N.T. wastes. The Department of Zoology of the University of Illinois for providing for the checking of the results with the second sample of red liquor while the author was in the armed forces, and Dr. C. J. Goodnight and M. L. Goodnight conducted the check experiments.

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THE EFFECT OF MOONLIGHT ON FISHING SUCCESS IN FISH LAKE, UTAH

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ABSTRACT

Partial creel-census records of Fish Lake, Utah, for the seasons of 1941-1943, were analyzed for evidence of a relationship between moonlight and fishing success. For both trolling and fly-fishing, the difference in the catch at times of new and full moons was not significant. The fly-fishing catch at times of first quarter moons (1.69 fish per man-trip) was significantly less than the mean catch at times of adjacent new and full moons (3.87 fish per man-trip); mean difference, 2.19 ± 0.675; value of *t*, 3.244. It is probable that light is the essential factor in producing the observed effect on fly-fishing at times of first quarter moon. This type of fishing is done almost exclusively after dark. A high ridge on the east shore of the lake protects the fishing area from the light of the full moon during effective fishing time, but the area is exposed to the light of the first quarter moon. Suggested explanations for the mode of operation of moonlight in reducing the catch are discussed.

INTRODUCTION

In recent years, there has been a notable increase in the acceptance by sportsmen of the belief that the moon has an adverse effect on fishing success. The only scientific report bearing on this question which has come to the attention of the writer is that of Mottley (1938). Mottley studied the fishing records of Paul Lake, British Columbia, and reported his findings under the title, "Does the full moon affect rainbow trout fishing?" The answer to this question was not entirely satisfactory, as may be judged by the following quotation from the report: "From the foregoing data it may be concluded that some factor associated with the occurrence of the full moon does affect rainbow trout fishing. The factor does not operate at every full moon but the evidence suggests that bright moonlight nights may be responsible for a reduction in the catch at certain times."

Fish Lake, Utah, affords an unusually favorable opportunity for a study of the effect of the moon on fishing, for fly-fishing at night is one of the principal activities of the anglers. A partial creel census has been made for the past several seasons by the Utah Department of Fish and Game and the U. S. Fish and Wildlife Service. Although the census was not directed toward a solution of the problem, the data readily lend themselves to that purpose. This paper is concerned with the evidence of an influence of moonlight on success by both trolling and fly-fishing. The method of handling the data is based on the assumption that, in any effect of the moon on fishing success, light would be the essential factor.

Methods

Fish Lake has been described in detail by Hazzard (1936). Fishing is mainly of two types: Trolling for rainbow and mackinaw trout in the daylight hours, and fly-fishing for rainbow trout from dusk until closing time at 9:00 o'clock, Standard Time. The fishing season opens about June 15, and closes September 30.

Owing to the large number of places where anglers leave the lake, it was impracticable to attempt a complete census. Ordinarily, an interviewer was stationed at the principal dock only at times which would yield a large number of records. Census records were obtained in 1938, and from 1940 to 1943, but the data of only the last 3 years are used here. Fishing success by trolling is stated in terms of fish per man-hour. For reasons given in an earlier paper (Wright, 1943) fly-fishing success is expressed as fish per man-trip.

To determine the effect of moonlight on trolling success, the mean catch per man-hour at times of full moon is compared with the corresponding figure at times of new moon. For each phase, the data from 5 days centering on the date of the phase are used. Owing to a number of peculiarities associated with evening fly-fishing on Fish Lake, it is necessary to use a modified plan for this type of fishing. The nature of the peculiarities will be stated later in the paper. Suffice to say here that the new moon is represented by 5 days centering on the date of the phase; full moon by the date of the phase, 1 day before and two after; first quarter by the date of the phase and 4 days after. In some instances, data are not available for one or more of the designated days. One phase in Table 3 is represented by only 9 man-trips. Ordinarily, this number would be considered too small to be representative, but the data are admitted because of essential agreement in the catches by both skilled and unskilled anglers. Few anglers fly-fish before the last week in July, so that the early part of the season is not reported in Table 3.

Confidence in the reliability of records of a partial creel census is based on the assumption that the anglers entering into a sample are representative of the population of anglers, and that the character of the population does not change markedly between periods of time to be compared. This ideal probably is not fully realized at Fish Lake, for the local, more skilled, fly-fishermen are convinced of the adverse effect of the moon, and doubtless tend to remain away at times of bright moonlight. A lowering of the average skill of the anglers at times of moonlight would appear in the census records as reduced success, and would accentuate any real reduction which might result from the influence of the moon. The available data do not permit numerical evaluation of this factor, but in the opinion of the writer it is not great enough to invalidate conclusions reached in this paper. This opinion is strengthened by the fact that two other uncontrolled factors, cloudiness on moonlight nights, and the legal creel limit, tend

to diminish any real difference between fishing success on dark and light nights.

TABLE 1.—*Fishing success by trolling at times of new and full moons*

Year	Phase of moon	Date	Man-hours	Fish	Fish per man-hour
1941	New	June 24	88	72	0.82
	Full	July 8	111	45	0.41
	New	July 24	64	20	0.31
	Full	August 6	77	26	0.34
	New	August 22	122	43	0.35
1942	New	June 13	441	241	0.55
	Full	June 28	202	110	0.54
	New	July 13	284	126	0.44
	Full	July 27	254	100	0.39
	New	August 11	262	112	0.43
	Full	August 25	198	54	0.27
	New	Sept. 10	74	58	0.78
	Full	Sept. 24	49	34	0.69
1943	Full	June 17	582	430	0.74
	New	July 2	848	565	0.67
	Full	July 17	680	469	0.69
	New	July 31	552	379	0.69
	Full	August 15	344	183	0.53
	New	August 30	196	146	0.74
	Full	Sept. 13	254	176	0.69
	New	Sept. 29	129	94	0.73

TROLLING

In Table 1 are given the essential creel-census data for trolling at times of new and full moons. Within each year the two phases are listed alternately, so that a rough idea of the magnitude of the differences in success can be obtainued by comparing alternate figures in the last column.

TABLE 2.—*Comparison of trolling success in terms of fish per man-hour at times of new and full moons*

New	Full	Difference
0.56	0.41	—0.15
0.33	0.34	+0.01
0.50	0.54	+0.04
0.44	0.39	—0.05
0.60	0.27	—0.33
0.78	0.69	—0.09
0.67	0.74	+0.07
0.68	0.69	+0.01
0.72	0.53	—0.19
0.74	0.69	—0.05
Mean: 0.602	0.529	—0.073

In order to facilitate comparison, the method of unique samples is employed in Table 2. Fishing success at each full moon is compared with the mean of success at the new moons preceding and following it, where possible, and elsewhere by that of the single nearest new moon. Use of the means of new moons minimizes the effect of seasonal changes in fishing success.

The figure for new moon exceeds that for full moon in 6 of the 10 pairs (negative differences), and there are no examples of agreement. The range of differences is from —0.33 to +0.07; mean difference is

—0.073, and standard error, 0.039. The sample value of *t* is 1.872, and the value of *t* at the 5-per-cent level for 9 degrees of freedom is 2,262. Hence the difference is not significant, and it is concluded that the data show no evidence of an effect of the full moon on trolling.

FLY-FISHING

There are a number of special conditions surrounding fly-fishing on Fish Lake, and a knowledge of them is essential to an understanding of the census records. Statements of the conditions follow:

1. *Shoreward migration.* The rainbow trout make a migration toward the shore at dusk, arriving in shallow water a short time before dark.
2. *Legal limitation.* Anglers are required to suspend fishing at 9:00 p.m., Standard Time.
3. *Fishing area.* A great majority of the anglers, and virtually all of those interviewed, fly-fish on the east shore of the lake. The littoral zone is extremely narrow on the east side, and the trout are concentrated in a small area, so that fishing success is greater than on the broad littoral of the west side.
4. *Character of the shore.* On the east shore, the beach is only a few yards wide. From the narrow beach, the shore rises abruptly to a ridge which is roughly 1,500 feet above the level of the lake. This ridge screens the fishing area from the light of the moon during the effective fishing time of the day before full moon and of following days. It screens part of the fishing area part of the time on the second day before full moon, but records of such days are not used in this report. Neglecting possible cloudiness, the fishing area is exposed to moonlight on the day of the first quarter and on the four days following.

TABLE 3.—*Fishing success by fly-fishing at times of new, first quarter, and full moons*

Year	Phase of moon	Date	Man-trips	Fish	Fish per man-trip
1941	New	July 24	62	155	2.5
	First quarter	July 31	54	64	1.2
	Full	August 6	61	148	2.4
	New	August 22	104	230	2.2
	First quarter	August 29	45	108	2.4
	Full	Sept.5	19	80	4.3
	New	Sept. 20	60	256	4.7
1942	New	July 13	41	94	2.3
	First quarter	July 20	24	24	1.0
	Full	July 27	25	47	1.9
	New	August 11	97	313	3.2
	First quarter	August 19	39	44	1.1
	Full	August 25	20	46	2.3
	New	Sept. 10	58	229	3.9
	First quarter	Sept. 17	9	10	1.1
	Full	Sept. 24	39	210	5.4
1943	New	July 31	106	535	5.0
	First quarter	August 8	51	179	3.5
	Full	August 15	57	261	4.6
	New	August 30	133	799	6.0
	First quarter	Sept. 7	37	56	1.5
	Full	Sept. 13	50	420	8.4
	New	Sept. 29	92	797	8.7

The basic data for fly-fishing at times of new, first quarter, and full moons are presented in Table 3. Pertinent comparisons are made more easily in Tables 4 and 5.

Table 4 compares fishing success at full moons with the means of success at times of adjacent new moons. There is agreement in one of the seven pairs of data, and the remaining six are divided equally between plus and minus values. The range of differences is from —1.3 to +1.5; mean difference is +0.04, and standard error, 0.419. Obviously, the difference is not significant, and it is concluded that the data show no effect of the full moon on fly-fishing on the east shore of the lake.

TABLE 4.—*Comparison of fly-fishing success in terms of fish per man-trip at times of new and full moons*

New	Full	Difference
2.4	2.4	0.0
3.4	4.3	+0.9
2.8	1.9	—0.9
3.6	2.3	—1.3
3.9	5.4	+1.5
5.5	4.6	—0.9
7.4	8.4	+1.0
Mean: 4.14	4.19	+0.04

TABLE 5.—*Comparison of fly-fishing success in terms of fish per man-trip at times of new and full moons with that at times of first quarter moons*

New-Full	First Quarter	Difference
2.4	1.2	—1.2
3.2	2.4	—0.8
2.1	1.0	—1.1
2.8	1.1	—1.7
4.6	1.1	—3.5
4.8	3.5	—1.3
7.2	1.5	—5.7
Mean: 3.87	1.69	—2.19

In Table 5, success at times of first quarter is compared with means of success at times of adjacent new and full moons. Note that the figure for first quarter is smaller than that for new and full moons in each of the seven pairs of data. The range of differences is from —0.8 to —5.7; the mean difference is —2.19, and the standard error, 0.675. The sample value of t is 3.244, which exceeds by far the value of t at the 5-per-cent level for 6 degrees of freedom. It is concluded that success of evening fly-fishing on the east shore of the lake was significantly less at times of first quarter moon than at times of new and full moons.

DISCUSSION

The findings presented above may be summarized briefly as follows: For the periods of time under investigation, (1) the difference in trolling catches at times of new and full moons was not significant; (2) the difference in fly-fishing catches at times of new and full moons was not significant; (3) the fly-fishing catch at first quarter moon was significantly less than at times of adjacent new and full moons. It is be-

lieved that these conclusions can be generalized safely for this body of water.

It is assumed that light is the essential factor in producing the observed effect on fly-fishing at times of first quarter moon. There is a possibility that some other factor associated with the first quarter phase is responsible, but that possibility seems to be relatively remote. If it could be shown that there is also a significant decline in trolling success at the first quarter, the claim for some factor other than moonlight would be strengthened, but evidence of a decline is lacking. The question could be answered if we had data from a large number of clear and cloudy nights at the first quarter. Thus, if the catch on cloudy nights proved to be significantly greater than on clear nights, the case for light would be established. The available data were examined for that purpose, and found wholly inadequate, for there were almost no cloudy nights to compare with clear nights. Pending further observation, light is accepted as the essential factor.

When anglers discuss the question of the effect of moonlight on fishing, they commonly mention two reasons for the effect: (1) with bright moonlight, the fish are able to feed all night, and are less hungry than usual during the day; (2) the light enables the fish to see the angler or his tackle, and to avoid them.

It is probable that the first of these suggestions has no basis in fact. We know that rainbow trout near the shore feed effectively without the aid of moonlight, for they take the lures avidly on the dark nights under a new moon. There is no reason to believe that the trout entering into the trolling fishery are less hungry during periods of moonlight, for no significant difference was found in the catches at times of new and full moons. For these reasons, the suggested explanation is rejected.

The second suggestion gains some support from our knowledge of fly-fishing success on the east shore at night. At times of full moon, when the fishing area is protected from the moonlight by a high ridge, fishing is quite as good as during the dark of the moon. When the light of the first quarter falls directly upon the fishing area, the catch per trip declines markedly. Moreover, anglers frequently report pronounced and rapid changes in success when a cloud obscures or reveals the moon. In a case of marked improvement in catch immediately after obscuration of the moon, it is reasonable to suppose that the fish were already inshore, and began to take the lure as soon as darkness covered the artificiality of the situation.

A third suggestion worthy of mention is that the trout may not migrate to the shore in large numbers at times of bright moonlight. This suggestion is based on analogy, for many animals suspend or resume activities as a result of minor changes in light intensity. Without doubt, the whole question of the mode of operation of moonlight in reducing the catch could be clarified by some simple observations under favorable conditions. An interesting speculation is whether, in the

absence of the high ridge on the east shore of the lake, the bright light of the full moon, (nine times as bright as at first quarter) would greatly augment the observed effect.

In the present state of our knowledge, it would be unwise to generalize broadly on the basis of conclusions reached in this paper. Special conditions on other waters might produce an effect quite different from that observed on Fish Lake. The danger of generalization is apparent in the failure of these results to explain the anomalous situation on Paul Lake (Mottley, 1938).

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CONTROL OF *HYDRODICTYON RETICULATUM* IN SMALL PONDS

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Abstract

A condition of algal nuisance in small ponds involving the water net, *Hydrodictyon reticulatum,* is described. A serial treatment with copper sulphate, in which daily applications of 0.33 p.p.m. of the chemical are made, resulted in the complete removal of the algae in five days. Sixteen ponds are kept free of algae by serial treatments with copper sulphate at regular intervals. The advantages of serial treatment over one-dose-treatment are discussed.

Algae assume major importance in the economy of any body of water. They are of primary importance in the initial stages of the food chains of our most desirable game and pan fishes. However, occasionally, when the proper conditions prevail, they can multiply and die in such abundance as to create conditions toxic to the fish life and prevent bathing and boating. Cases are known of cattle being killed by drinking lake water during such periods of rapid reproduction, growth, and death of algae.

During the middle of July 1940, an extreme growth of algae was noted in the rearing ponds of the Spooner (Wisconsin) hatchery. The water supply for the 16 fish-rearing ponds, obtained from the Yellow River flowage, enters two intakes and flows down a concrete flume, with bulkheads feeding the individual ponds. Only enough water is used to keep the ponds fresh and compensate for evaporation. Consequently, the flow through the ponds is negligible, and, as the water temperature increases, the reproduction of the algae increases.

The alga which was present in the ponds was the water net, *Hydrodictyon reticulatum* (L.) Lagerheim. In its characteristic form, it consists of a sheet of lace-like tissues, made of slender green cells that meet at their ends, ordinarily by sixes, forming hexagonal meshes. Reproduction is unique, in that new colonies are formed by multiple division of the contents of single cells. This division results in a complete miniature net formed in a single cell which, upon escape, grows merely by increase in size. Under the proper conditions, this method of multiplication will result in immense masses of water net in a very short period of time.

Toward the latter part of July, the net was of such density that fish in the rearing ponds, especially fingerling muskellunge, were being caught in the meshes and killed. The mat was between 6 and 8 inches thick. Up to this time, part of the alga growth was removed by hand by hatchery employees, but little progress was made. It was decided that removal by chemical means offered the only satisfactory solution.

FIGURE 1.—Pond before treatment showing mat of *Hydrodictyon reticulatum.*

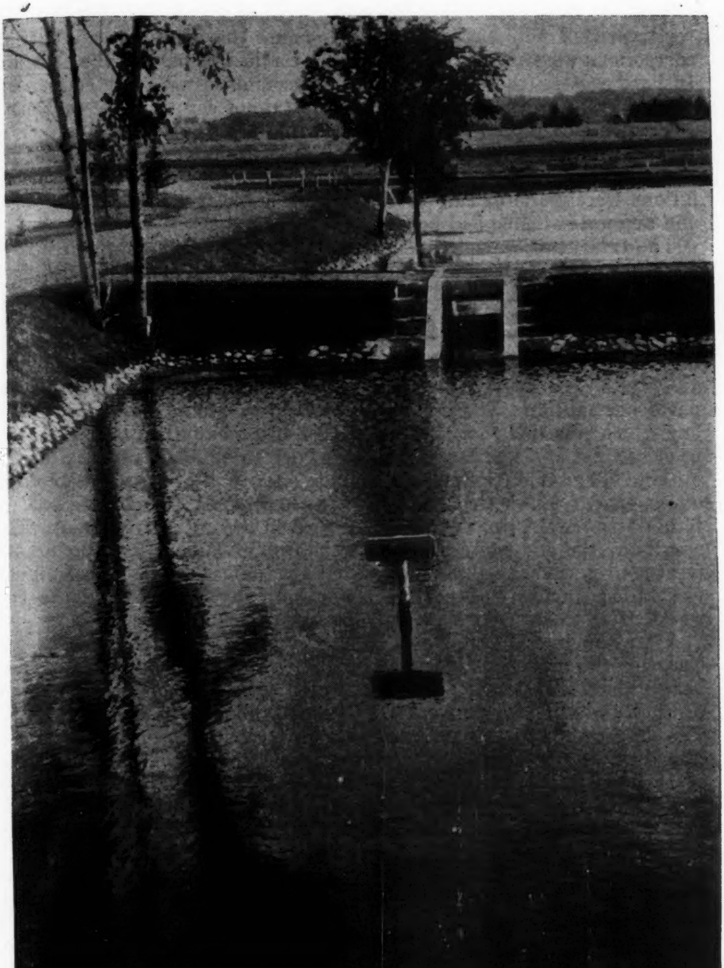

FIGURE 2.—Pond free of *Hydrodictyon reticulatum* after serial treatment.

Prior to the time of this decision, preliminary tests had been made for treatment with copper sulphate. Since the pond water is soft, no corrections were needed to compensate the loss of part of the chemical. In hard waters, the calcium carbonate combines with any copper sulphate used, to form an insoluble precipitate of copper basic carbonate. For each 1.72 p.p.m. of calcium carbonate in the water, 1 p.p.m. of copper sulphate is removed. Therefore, in such cases, the higher the carbonate, the greater the dosage of copper sulphate reguired. Calculations were made of rate of water flow, cubic feet of water in ponds and amounts of chemical needed.

The treatment reported was made on only one pond, which was 40 feet long and 25 feet wide and had a maximum depth of 3½ feet. The condition of the pond before treatment is shown in Figure 1. Because the pond contained a large number of muskellunge fingerlings, approximately 4 inches long, it was decided to give a serial treatment instead of a single dose. The initial treatment, given on the morning of July 30, consisted of a dose of copper sulphate amounting to 0.33 parts per million The copper sulphate was placed in a cheesecloth bag which was tied to a long pole. The bag was pulled over the pond in criss-cross and spiral patterns, in order to obtain a uniform distribution. The same treatment was made on a total of 5 successive days, at the end of which time the pond was completely free from algae. A total dosage of 1.65 p.p.m. had been used in the entire treatment. The results at the end of treatment are shown in Figure 2. During the treatment period the algae were killed gradually. Not one muskellunge was killed during the treatment nor had any died during the two weeks after treatment, when only periodic checks were made.

After the initial treatment, calculations were made to serve as a basis for the treatment of all 16 ponds by applying concentrated copper-sulphate solution to the intake water which was fed to each pond through the concrete flume. The calculated dosage was still 0.33 p.p.m. The copper sulphate was applied over a period of 40 minutes by means of a dropping bottle placed over the water intake. The entire series of 16 ponds was cleared of algae in 7 days by this method and was kept clear by occasional treatment every 4 or 5 days.

It is believed that the failure of the treatment to kill fish was due to the use of serial treatment instead of a one-dose treatment. The algae were destroyed so gradually that the dissolved oxygen in the ponds (10.0 to 11.0 p.p.m.) more than met the demand created by the decomposing dead algae. Furthermore, the destruction of the algae in small amounts each day possibly reduces the danger of fish loss from toxic products that may be released by the dead algae.

EVALUATION OF SALMON FLESH AND SALMON VISCERA IN THE DIET OF CHINOOK SALMON FINGERLINGS

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ABSTRACT

The addition of salmon flesh and salmon viscera to a diet for chinook salmon fingerlings produced growth equal to that resulting from all-meat diets. The cost of production was reduced considerably. Salmon flesh did not prevent the appearance of an anemic condition and therefore is considered deficient in the anti-anemia factor. Some evidence obtained indicated that salmon flesh might have a destructive influence upon the anti-anemia factor present in other foods. This effect may be similar to that exhibited by other frozen fish upon vitamin B_1. Salmon viscera in the diet prevented anemia in some instances and is presumed, therefore, to contain some anti-anemia factor. However, it cannot be fed as a sole diet over long periods at the Leavenworth, Washington, Station.

INTRODUCTION

Feeding problems are becoming increasingly difficult at fish hatcheries because of the present war conditions. The supplies of fresh meats suitable for feeding fish have become greatly depleted and the cost of those items that are available has increased markedly. Dry concentrates, extensively used during the past few years as substitutes for fresh meats, are now almost impossible to procure in certain sections of the country. It is essential that additional substitutes for fresh meats be found if hatcheries are to continue to operate on an economical basis. During the summer of 1943, certain diets were evaluated at the U. S. Fishery Station at Leavenworth, Washington, in an attempt to discover cheaper and more efficient combinations for feeding salmon fingerlings.

Salmon flesh and salmon viscera offer a ready source of fish food on the Pacific Coast. An abundant supply of salmon flesh is available at the various hatcheries that carry on spawning operations and may be obtained for the cost of hauling. Salmon viscera is a by-product of the canning industry and is sold rather cheaply. Fish hatcheries offer a market for this product that otherwise would have little value except as a fertilizer.

The use as food for trout of some species of frozen fish has been fatal (Gutsell, 1940; Tunison *et al*, 1938, 1942; Phillips, *et al*, 1940; Wolf, 1942). The cause for the losses was traced to a deficiency of vitamin B_1. Excellent reviews have been published concerning this condition in trout and its relationship to a similar deficiency in other animals (Tunison, 1942; Wolf, 1942; Alexander *et al*, 1941) and

therefore an extensive discussion would not appear warranted in this paper.

Donaldson (1939, 1940) has successfully used salmon flesh and salmon viscera in diets for young chinook salmon. He was able to rear salmon over a 20-week period on salmon viscera alone. However, when using salmon flesh in the diet he recommended the addition of about 20 per cent beef liver.

Procedure

Small wooden troughs were stocked in May with an initial weight of 500 grams of chinook-salmon fingerlings, equivalent to 929 fish. All fish in each trough were weighed at 2-week intervals and the gains, mortalities and conversion factors were calculated at that time. These three indices were used to evaluate the various diets.

The daily quantity fed to the chinook-salmon fingerlings was based upon the recommendation of Tunison (1940) for rainbow trout. It was found through practice and observation that chinook salmon exhibit the most economical growth when fed an amount of food varying from the value given in Tunison's table to two per cent below that value. The food intake level was re-estabilshed at weekly intervals based either upon the actual weight of the fish, when available, or upon an estimated weight for the odd weeks when the fish were not weighed. All diets were prepared for 2-day intervals. The fish were fed four times daily until the middle of July, after which they received three feedings daily. The fish were not fed on Sunday.

A small potato ricer was used for feeding. By this method it was possible to duplicate hatchery procedure. Two per cent salt was added to each diet for the purpose of binding the mixtures.

The fish were permitted to grow until a total weight of 1,500 grams per trough was reached. Weights were reduced to this level on each weighing day throughout the balance of the experimental period. The fish were examined frequently for evidence of disease and, after the middle of July, periodic erythrocyte counts were made.

The growth of the fish was expressed as percentage gain based upon the average weight per fish. By this method an excessive loss would not distort the actual gain made by the fish.

The amount of food fed and the total gain of the fish for the period were used to determine the conversion factors. The total gain of the fish included the weight of those that died during the period. The weight of dead fish in grams for a period was estimated from the average weight of the individual fish and recorded number lost.

The cost of production was calculated from the conversion factor and the cost of the diet per pound as purchased. The cost of the diets and the separate ingredients are shown in Table 1.

The majority of the experiments were conducted for a 20-week period. Some of them, however, were begun at a later date and so did not extend throughout the entire time interval as noted in Table 2.

TABLE 1.—*Composition of diets expressed as percentages by weight*

Diet number	Beef liver	Hog Speen	Salt	Salmon flesh	Salmon viscera	Commercial fish meal	Dry feed[2]	Cost per pound[1]
1	98.0	....	2.0	....	....	....	....	$0.098
2	49.0	49.0	2.0	....	....	....	....	0.079
3	12.5	12.5	2.0	73.0	....	....	....	0.031
4	12.5	12.5	2.0	....	73.0	....	....	0.033
5	7.5	7.5	2.0	30.0	30.0	....	23.0	0.027
6	12.5	12.5	2.0	25.0	25.0	....	23.0	0.0385
7	15.0	15.0	2.0	20.0	20.0	....	28.0	0.039
8	25.0	25.0	2.0	18.0	20.0	10.0	....	0.051
9	25.0	25.0	2.0	....	25.0	....	23.0	0.058
10	25.0	25.0	2.0	25.0	....	....	23.0	0.057
11	25.0	25.0	2.0	48.0	....	....	....	0.048
12	25.0	25.0	2.0	....	48.0	....	....	0.049

[1]Cost per pound based upon following purchase prices per pound:

Beef liver	$0.100	Salt	$0.010
Hog spleen	0.061	Wheat shorts	0.022
Salmon flesh	0.015	Commercial fish meal	0.040
Salmon viscera	0.018		

[2]Dry feed mixture composed as follows (No. 6a):

Wheat shorts	50%	Fish meal	50%

The beef liver used in all experiments had been condemned for human food because of infestation with the liver fluke, *Fasciola hepatica*. The liver was denatured by dyeing as required by law.

All data have been summarized by two-week periods for comparative purposes, and are listed in Table 2. The data were analyzed by analysis of variance and this measure has been used to compare differences. Where differences are stated, such conclusion was reached with the aid of this measure of variation.

DISCUSSION

The addition of 73 per cent salmon flesh to a diet containing 12.5 per cent each of hog spleen and beef liver resulted in an anemic condition of the fish by the end of the experimental period. As shown in Table 2, the actual erythrocyte count was not alarming, but previous counts had shown that there was a gradual downward trend. In comparison to the meat controls, the gain in weight was equal or greater, and the cost of production was definitely lowered. The loss was higher than would normally be expected, but was comparable to that of the meat controls.

The addition of salmon viscera to a similar diet resulted in a normal erythrocyte count of the fish at the end of the test period. An anemia did develop in this lot during the experiment, but it was corrected quickly by a change in the method of feeding. Mixtures containing high levels of salmon viscera are quite fluid and upon passage through a ricer they become finely suspended in the water. The smaller fish are able to utilize this food but as the fish become larger a greater portion of the diet is lost. As a consequence, in this experiment, as the fish grew larger the growth rate dropped considerably and the fish became anemic. The method of feeding was changed from a ricer to a

TABLE 2.—*Summary of feeding experiments using salmon products*

Diet number	Average 2-week gain (per cent)	Average 2-week loss (per cent)	Average 2-week conversion factor[1]	Cost per pound fish flesh produced	Blood count at end of experiment[3]	Number of weeks on experiment
1	19.6	1.01	4.7	$0.46	1,113,000	20
2	16.2	2.53	6.2	0.49	....	20
3	19.6	1.58	4.9	0.15	912,000	16
4	17.1	0.93	6.7	0.22	1,140,000	16
5	19.9	1.49	6.9	0.19	757,000	16
6	24.5	1.16	4.3	0.16	975,000	14
7	19.2	2.17	5.0	0.20	1,043,000	16
8	20.9	0.48	4.1	0.21	1,117,000	20
9	19.8	0.37	4.6	0.26	1,177,000[2]	20
10	18.8	0.47	4.8	0.27	1,073,000[2]	20
11	19.5	0.59	4.6	0.22	987,000	20
12	19.2	0.95	5.0	0.25	1,142,000	20

[1]Conversion factor represents the number of pounds of food required to produce one pound of fish flesh.
[2]These counts were made the end of July. No subsequent counts were made.
[3]Per cubic millimeter.

spoon. There was an almost immediate response in the growth rate and the anemia rapidly disappeared.

A series of experiments were included to determine the minimum amount of beef liver necessary to maintain fish life when salmon products were used as substitutes. Dry feed mixture No. 6a supplemented the fish and meat products.

A diet containing 7.5 per cent each of beef liver and hog spleen and 30 per cent each of salmon flesh and salmon viscera produced a mortality in excess of the expected normal. The fish were severely anemic at the conclusion of the experiment.

A second experiment in this group contained 12.5 per cent each of beef liver and hog spleen and 25 per cent each of the two salmon products. An anemia was present at the end of the experiment although it was less severe than the anemia that developed in the fish fed at the lower level of the meat products.

The last experiment in this series was fed a diet composed of 15 per cent each of the meat and 20 per cent each of the salmon products. The erythrocyte content of the blood remained almost normal, although slightly below the usual 1,150 red cells per cubic millimeter of blood.

In all three cases described above, the substitution of salmon flesh and salmon viscera for a portion of the usual meats produced gains that were at least equal to the meat controls. The cost of production was definitely reduced. However, there does appear to be a limit as to the extent they may be employed. The substitution of salmon flesh and salmon viscera at high levels resulted in an anemic condition. This is in agreement with Donaldson (1940) in that he stated that salmon flesh should be fed with some beef liver. However, the same author (1939) was able to raise chinook salmon for a 20-week period on salmon viscera alone. This conclusion is not supported by the present series of experiments. Indications are that salmon viscera does possess some anti-anemic properties, but that it is not as potent a source as beef liver.

No evidence of a deficiency of vitamin B_1 was noted even though our procedure of diet preparation would allow a maximum opportunity for the fish products to act. It is possible that salmon flesh and viscera do not exert the same effect upon vitamin B_1 that is shown by other fish products. These superficial observations, however, do not reveal the vitamin content of the fish bodies and before definite conclusions may be reached the fish should be analyzed by chemical means.

The past three seasons a mixture designated as "pond diet" has been fed at Leavenworth. This diet is composed of 25 per cent each of beef liver and hog spleen, 20 per cent salmon viscera, 18 per cent salmon flesh, 10 per cent commercial fish meal and 2 per cent salt. In comparison to the meat controls, this diet gave excellent results, as the growth rate was equal, the loss lower and the cost of production less than half. The fish were not anemic.

Likewise the addition of 25 per cent salmon viscera to a diet containing 25 per cent each of beef liver, hog spleen and a dry feed mixture, resulted in growth equal to the meat controls, a low loss and a comparable conversion factor. The cost of production was greatly reduced. Erythrocyte counts the early part of August showed the absence of anemia. Subsequent counts were not made.

A diet similar to that above except salmon flesh replaced salmon viscera, produced comparable results as to loss, growth and cost. However, blood counts made the early part of August were somewhat lower than the meat controls, but still above the apparent dangerous level of 800,000 cells per cubic millimeter of blood. Subsequent counts were not made.

When half of the diet was supplemented by salmon flesh, the growth rate was equivalent to the meat controls. The loss was about average for the series of experiments and the cost of production was reduced. An anemia was noted at the end of the experiments. Since the diet contained 25 per cent each of beef liver and hog spleen, there is a strong possibility that salmon flesh may have some property destructive to the anti-anemia factor of other foods. This property may be similar to that shown by other fish products upon vitamin B_1. This supposition is partly borne out by the appearance of a slight anemia earlier in the experimental period in the fish fed the diet containing 25 per cent salmon flesh and 25 per cent each of beef liver and hog spleen. Assuming salmon flesh does destroy the anti-anemia factor of other foods, then those diets containing salmon flesh and viscera should also be affected. If the flesh were removed, the viscera should prove to be a more potent source of the anti-anemia factor than is indicated by the reported experiments. If future trials bear out this assumption, it should be possible to test more adequately for the anti-anemia factor by feeding a diet containing salmon flesh. This would destroy the anti-anemia factor, but presumably allow the other requirements to remain in the diet. A satisfactory test diet has been one of the greatest needs in past searches for this essential.

In support of this hypothesis an experiment similar to the one described above, but in which salmon viscera replaced salmon flesh, gave a normal red cell count of the fish's blood at the conclusion of the experiment.

The writers wish to express their appreciation to Dr. F. F. Fish for his helpful suggestions and criticisms throughout the course of the experiments and for his critical review of the present paper. Thanks are also extended to Roger E. Burrows for his help and suggestions.

Conclusions

1. The addition of salmon flesh and salmon viscera to a diet for hatchery-reared chinook salmon resulted in growth at least equal to an all-meat diet. The loss in the majority of cases was lowered and the cost of production was definitely reduced.
2. Salmon flesh apparently has no anti-anemia property. In fact, indications are that it will destroy the anti-anemia properties of other foods.
3. Salmon viscera does apparently possess some ability to prevent anemia, although it cannot be fed for long periods at the Leavenworth station without the addition of some beef liver.
4. If the indications that salmon flesh destroys the anti-anemia factors of other foods are true, it is possible that if the flesh was removed from the meat level diets, salmon viscera would prove a more potent source of anti-anemia factor than is indicated by the reported experiments.
5. When feeding high levels of viscera, the physical consistency of the diet demands a careful feeding technique or an excessive loss of food will occur, followed by low gains and anemia.
6. A diet designated as "pond diet" proved an economical and satisfactory mixture for hatchery-reared chinook salmon.
7. By observation, none of the characteristics of a vitamin B_1 deficiency were seen. Chemical tests were not made.

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EXAMPLES OF THE USE OF TWO-WAY FISH WEIRS IN MICHIGAN[1]

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Abstract

Descriptions and reasons for the installation and operation of the most important types of two-way fish weirs used in Michigan are presented, with a summary of the results obtained and the conclusions reached as a result of the operations.

Five weirs are in operation at the present time at the Hunt Creek Fisheries Experiment Station. Four of the weirs (one of a self-cleaning rotary type) installed near the mouths of tributaries are used to determine the movements of native and planted fish between the tributaries and the main stream, and the fifth weir was installed at the outlet of East Fish Lake to block the reentry of undesirable species into the lake. During 1943, a total of 1,161 brook trout (fingerlings and fish approaching legal size) moving downstream and 292 moving upstream were captured in these weirs. The contribution by tributaries to the main stream is evident.

The Muskegon River weir was installed just below Houghton Lake for the purpose of determining the extent of the migration of fishes to and from Houghton Lake and the role of Houghton Lake in contributing to the fish stock of the impoundment formed by the Reedsburg Dam (about 11 miles below Houghton Lake). There is some migration of fish between Houghton Lake and the Muskegon River in the spring and early summer; this movement appears to be associated with spawning. Common suckers and redhorse made up 92.5 per cent of the total upstream and downstream migrants in 1939 and 1940, while only 3.0 per cent was composed of the important game species, northern pike and yellow pikeperch.

A weir was installed in the Ontonagon River below Lake Gogebic to determine the nature and extent of the movement of yellow pikeperch and other fish to and from the lake. Except for suckers, there was no significant loss of fish from Lake Gogebic by migration down the outlet. During the period of operation of the weir, more game fish migrated into the lake than were counted leaving the lake.

Occasionally during low water and following strong on-shore winds, temporary sand bars may develop across the mouth of the Platte River where it enters Lake Michigan. A weir was installed on the Platte River to determine the extent of fish migration and to what extent this migration was blocked by sand bars. During the 20 months that the weir was in operation, fish were able to enter the river at all times. Unless future observations indicate a change of conditions, no improvements need be made in the channel of the river mouth.

Introduction

One of the tools at the disposal of the biologist is the two-way fish weir. Foerster (1929), Taft (1934), Shetter (1938), Rayner (1942), Raney and Webster (1942), Carbine (1942 and 1943), and others, have recognized the usefulness of the structure in fishery research. Since 1936, more than a dozen different weirs have been used in Michi-

[1]Contribution from the Michigan Institute for Fisheries Research.

FIGURE 1.—The East Fish Lake weir (looking downstream). The weir is located in the outlet about 50 feet below the lake. Fish moving downstream are taken in either of the two traps at the side, and fish moving upstream are caught in the trap at the apex of the V. The purpose of the weir is to prevent re-entry into the lake of all fish other than trout (which are passed over the weir), and to determine the number of trout that leave the lake.

gan to provide information on many controversial questions of fishery management. The value of these structures in studying diverse fishery problems can be illustrated best by some examples of the information that may be obtained on such problems as: (1) the role of tributary streams in contributing to the fish supply of lakes and streams; (2) the sex ratio, size range, and number of fish in the spawning runs of several species; (3) the efficiency of natural reproduction as estimated by trapping all spawning adults and resulting young; (4) the migratory tendencies of hatchery-reared fish as compared with native fish; (5) the growth and survival of marked fish; (6) the effects of temperature, water level, and other physical factors upon the spawning run; and (7) the abundance of certain undesired species of fish (the destruction of undesired species taken by means of weirs also provides a method of partial control).

The purpose of this paper is to give the reasons for the operation of weirs at the Hunt Creek Fisheries Experiment Station, at the outlet of Gogebic Lake, on the Muskegon River below Houghton Lake, and

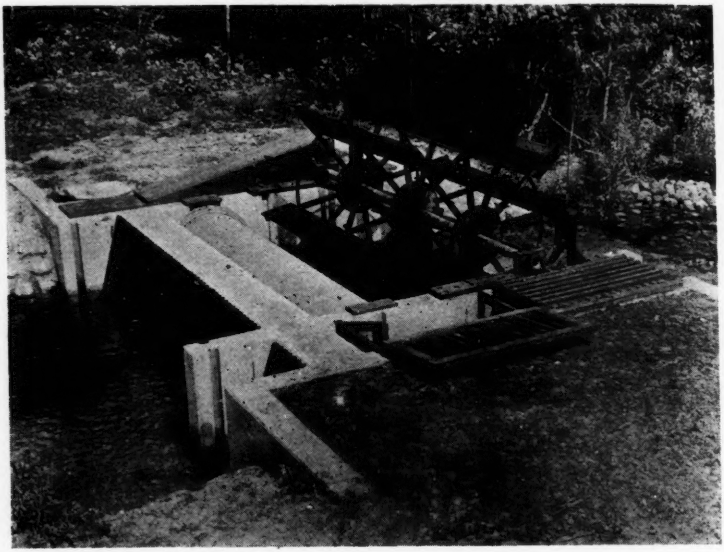

FIGURE 2.—The Fuller Creek weir. The revolving drum (made of quarter-inch-mesh wire screen) can be seen between the trash rack and the water wheel which operates it. A reverse gear causes the drum to turn with the current. It is self-cleaning, except for the larger pieces of debris which are caught on the trash rack and must be removed by hand. The cover of the downstream trap is open.

on the Platte River, to summarize the results obtained, and to present the conclusions reached as a result of the operations. A brief description of the type of weir used at each site is also given.

HUNT CREEK WEIRS

Five weirs are in operation at the present time at the Hunt Creek Fisheries Experiment Station of the Institute for Fisheries Research. One weir, located at the outlet of East Fish Lake, was installed primarily to block the re-entry of undesirable species into the lake after its population was eliminated by poison and brook trout were planted. Data on migration are also available from its operation. The other four weirs (one of a self-cleaning rotary type) installed near the mouths of tributaries are being used to determine the movements of native and planted fish between the tributaries and the main stream.

Description of weirs.—The weirs on the tributaries of Hunt Creek are of two types; a modified V-shaped structure, constructed from lumber and wire screen built on single sheet-piling to prevent under-

cutting (Fig. 1); and a self-cleaning rotary type built of concrete over Wakefield piling (Fig. 2). Where the volume of water is relatively small and uniform, the first-mentioned type operates efficiently with a minimum of care. Where the flow is large and is likely to fluctuate, a self-cleaning rotary screen is very desirable, since it will eliminate much of the labor necessary to keep the screens cleaned in periods of high water. One of the stationary weirs can be installed for between $40 and $70, while cost of a rotary, self-cleaning weir such as installed in Fuller Creek (Fig. 2), is approximately $1,000. The initial high cost of the rotary weir will be offset by the saving in labor after installation since this type of weir will not require the constant cleaning demanded by a stationary structure in a similar location.

Results.—During 1943, a total of 1,161 brook trout moving downstream and 292 moving upstream were captured in these weirs. The majority of these fish were fingerlings or fish approaching legal size. All were native trout. The contribution by the tributaries to the main stream is evident. Details of this investigation which is still in progress will appear in a subsequent paper.

The Muskegon River Weir

Houghton Lake, located in Roscommon County, has always had a reputation as one of the best northern pike lakes in Michigan. The decline in the abundance of northern pike in 1931 and again in 1935, as demonstrated by creel censuses taken by Conservation Officer Thomas White since 1928, resulted in numerous complaints by fishermen and resort owners who believed that adult northern pike left Houghton Lake to spawn in the Muskegon River and that neither the adults nor the resulting young returned to the lake. For several years the Houghton Lake Chamber of Commerce prevented fish from leaving Houghton Lake by placing blocking bars across the Houghton Lake dam. Considerable pressure was brought to bear upon the Department of Conservation to make a survey of conditions and to prevent the alleged movement of fish from the lake.

At about this same time another problem arose. The Game Division of the Michigan Department of Conservation proposed to construct a dam on the Muskegon River approximately 11 miles below Houghton Lake which would flood several thousand acres of river bottom and marsh and back the water up within a short distance of the Houghton Lake dam. This impoundment, which was subsequently created late in 1940 and is known as the Reedsburg Dam, is used for the improvement of the habitat of water-fowl, fur-bearing animals, and fish. In the winter of 1938-1939, it was suggested by Mr. F. A. Westerman, Chief of the Fish Division, that the Institute for Fisheries Research should install a two-way fish weir on the Muskegon River below Houghton Lake for the purpose of determining: (1) the extent of the migration of fishes to and from Houghton Lake; (2) the role of Hough-

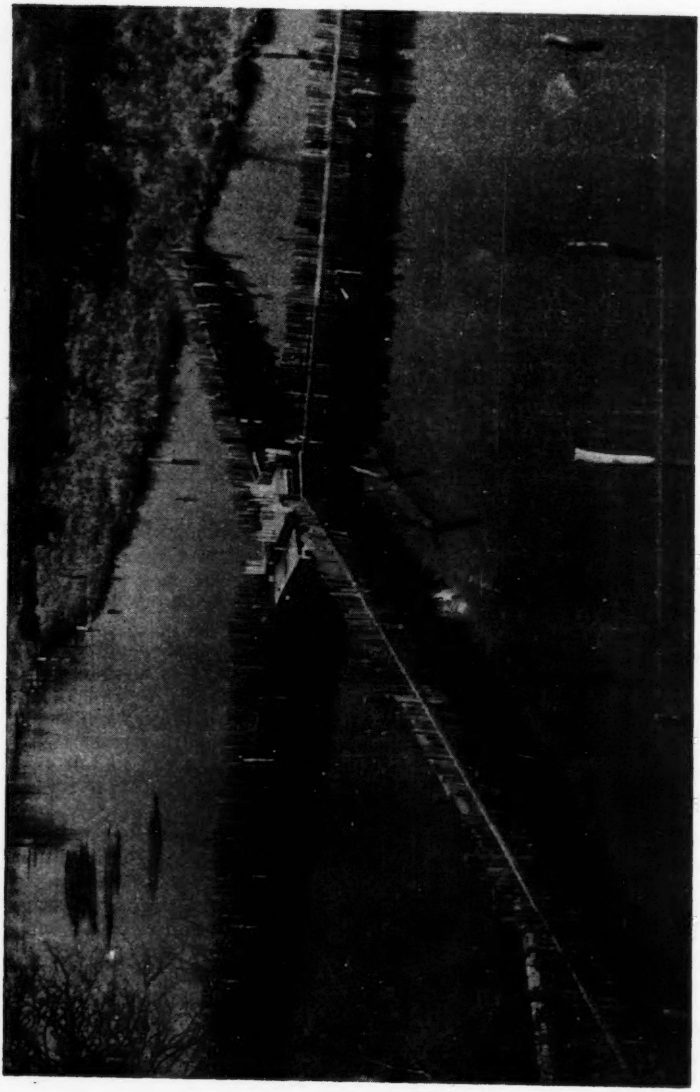

FIGURE 3.—View of the Muskegon River weir, looking downstream. The traps are located in the center of the weir, at the apex of each V.

ton Lake in contributing to the fish supply of the new impoundment formed by the proposed Reedsburg Dam; and (3) the probable effect of a dam on the fish movements, and the fish population of Houghton Lake, the new impoundment, and the Muskegon River.

A two-way fish weir was installed and was operated in the Muskegon River, approximately one-eighth of a mile below the Houghton Lake dam, from April 7 until June 19, 1939, and from March 31 until July 11, 1940. At the site selected for the weir, the river was 120 feet wide, with a maximum depth of 3 feet. The bottom was composed of clay covered by from 6 inches to 2 feet of sand.

Description of weir.—In 1939, the weir consisted of a single wing extending across the river at an angle of about 25 degrees with the current. The traps were connected to the end of this main arm. Numerous changes were made throughout 1939 in order to increase the efficiency of the structure. These changes resulted finally in a double-**V** weir with the traps located near the center of the main wing, at the apex of each **V**. We were not too well satisfied with the design of the 1939 weir. Consequently, in 1940 a much improved double-**V** weir was designed and installed. The weir consisted of a 12- by 5-foot trap, located approximately in the center of the river, with the long axis parallel to the river banks (Fig. 3). A partition of blocking bars divided the trap into equal parts, each 6- by 5-feet. The trap on the upstream side of the weir captured all fish moving downstream, and the other trap captured all fish moving upstream. Four wings or blocking arms, each approximately 85 feet long, and set at an angle of about 25 degrees with the current, connected the corners of the trap with the shore. This arrangement resulted in a double-**V** weir, with the trap forming the apex of each **V** (Fig. 3). The blocking bars which were installed in a lumber frame consisted of 1- by 2-inch wooden slats, pointed at one end and driven into the bottom. The weir was constructed in such a manner that slats could be removed or driven farther into the bottom at any time. The distance between the blocking bars was 1½ inches. This spacing allowed all but the mature individuals of the larger species free movement, either upstream or downstream. A 4- by 4-foot removable gate which rested on sheet-piling projecting about 1 foot above the bottom, formed the entrance to each trap. Each gate was built so that it could be lifted out of the trap (by sliding upward) to facilitate cleaning of the weir. The cone-shaped funnel, made of ½-inch-mesh wire screen, was attached to the bottom half of the gate. The apex of the funnel projected into the trap. The funnel was 24 inches long, with a diameter of 6 inches at the small end. The large end was 36 by 24 inches. The upper half of the gate was made of 1- by 2-inch slats, spaced 1½ inches apart. The total cost of materials for the completed 1939 weir was $89.84, and for the 1940 weir, $126.06. No estimate is available of labor and transportation costs (furnished in part by the Civilian Conservation Corps Camp Houghton Lake, of the Houghton Lake State Forest).

TABLE 1.—*Total catch and the size range of each species taken in the Muskegon River weir between April 7 and June 19, 1939, and between March 31 and July 11, 1940, all dates inclusive*

Common name	Scientific name	Number of fish captured					Total length (inches)		
		1939		1940		Total			
		Down-stream trap	Up-stream trap	Down-stream trap	Up-stream trap	1939-1940	Mini-mum	Aver-age	Maxi-mum
Common sucker	*Catostomus c. commersonii*	902	435	4,393	856	6,586	11.0	18.5	25.0
Northern redhorse	*Moxostoma aureolum*	117	28	906	373	1,424	9.8	18.6	22.3
Dogfish or bowfin	*Amia calva*	150	10	113	66	339	21.5	25.2	30.5
Northern pike	*Esox lucius*	13	16	140	48	217	17.2	21.8	40.2
Yellow pikeperch	*Stizostedion v. vitreum*	16	....	23	6	45	10.9	17.7	23.2
Bullheads	*Ameiurus* sp.	8	....	8	2	18	....	....	....
Channel catfish	*Ictalurus l. lacustris*	....	1	10	....	11	37.6	38.5	39.7
Rock bass	*Ambloplites r. rupestris*	3	....	5	3	11	....	....	....
Bluegill	*Lepomis m. macrochirus*	1	....	1	....	2	....	....	....
Largemouth black bass	*Huro salmoides*	....	....	1	....	1	....	....	....
Black crappie	*Pomoxis nigro-maculatus*	....	....	1	....	1	....	....	....
Longnose gar	*Lepisosteus osseus oxyurus*	....	....	1	....	1	....	....	....
Yellow perch	*Perca flavescens*	....	....	....	1	1	....	....	....
Spotted sucker	*Minytrema melanops*	1	....	....	....	1	....	....	....
Total		1,211	490	5,602	1,355	8,658	....	....	....

Results.—During 1939 and 1940, 15 species of fish were taken in the Muskegon River weir (Table 1). Common suckers made up the bulk of the run followed by redhorse suckers, bowfin, northern pike, and yellow pikeperch in that order of abundance. These five species made up 99.4 per cent of the total downstream run of fish and 99.6 per cent of the total upstream run for the 2-year period. Very few other fish were taken in the weir although over 60 species are listed from Houghton Lake and the Muskegon River. The small number of species taken was partially due to the wide spacing of the blocking bars of the weir which allowed the smaller varieties such as perch, blue gills, minnows, etc., to pass through the weir.

In 1939 and 1940, all northern pike, yellow pikeperch, and channel catfish were "jaw-tagged." Other fish taken in the traps in 1940 were marked by clipping fins. Different fins were clipped on upstream and downstream migrants to permit future identification of all fish which passed through the weir. After marking, each fish was released in the direction in which it had been moving when captured.

Because of faulty construction, no fish were taken in 1939 in the weir during the first 13 days after completion, although the downstream migration (which begins earlier than the upstream movement) started shortly after the weir was completed. For example, observations disclosed that if one sucker found an opening in the trap and escaped, the remaining suckers followed it. Eight different types of trap entrances were installed before we were able to hold substantially all of the fish that entered the traps. The funnel entrance finally devised was most satisfactory (the construction of this entrance was described earlier). No doubt many fish that would normally have moved downstream in 1939 were not recorded because of the faulty entrances to the traps.

Another fault of the Muskegon River weir was that it was not always "fish-tight." During periods of high water, holes developed due to undercutting. The weir was checked daily and all blocking bars in the weir were driven farther into the bottom when undercutting was noted. Maintenance of a "fish-tight" weir in a flowing stream having a sand bottom is extremely difficult unless sheet-piling is used. Several northern pike that were tagged going downstream were captured in Houghton Lake by anglers in 1940 before the weir had been removed. These fish, and undoubtedly other marked and unmarked fish, passed through holes in the weir and were therefore not recorded.

Data on the upstream and downstream migration of fish in the Muskegon River are not complete because the weirs were not in operation throughout the entire year. Fish were still moving upstream when the weirs were removed in 1939 and 1940, and it is possible that more of the fish would have been recorded as returning to Houghton Lake if the weirs had been in operation for a longer period. In 1939 and in 1940, several northern pike that were tagged going downstream and

not retaken going upstream, were recovered in Houghton Lake by anglers after the weirs had been removed. If the weirs had been left in longer each year, there might have been a better balance between the number of upstream and the downstream migrants. The main reason for removing the weirs when we did was the shortage of help and the pressure of other duties. The early removal was also prompted by the fact that so few game fish were captured in the weir.

The effect on the total catch of fish in the Muskegon River weir of the three factors discussed above, namely, (1) the faulty construction of the weir in 1939, (2) the fact that the weir was not always "fish-tight" in 1939 and in 1940, and (3) that the weirs were not in operation through the entire year, should be kept in mind when considering the data that follow.

The first fish were captured in the downstream trap of the weir in 1939, on April 19, 13 days after the weir had been in operation. The first fish were captured in the upstream trap on April 28. In 1940, the fish were taken in the downstream trap on April 2, the third day that the weir had been in operation, and the first fish were taken in the upstream trap on April 17. The heaviest run of downstream migrants (all species combined) occurred between April 19 and May 30, 1939, and between April 6 and June 7, 1940 (Table 2). The greatest run of upstream migrants took place between April 29 and May 27 in 1939, and between April 23 and June 7 in 1940.

In 1939, a total of 1,701 fish were taken in the traps of the weir—1,211 (80.5 per cent) in the downstream trap and 490 (19.5 per cent) in the upstream trap. Of the 6,957 fish captured in 1940, 5,602 (71.2 per cent) were moving downstream and 1,355 (28.8 per cent) were moving upstream. A total of 5,575 of the 5,602 fish that were taken

TABLE 2.—*The weekly catch of the most important speci*

	Common sucker				Northern redhorse				Dogfish			
	Downstream trap		Upstream trap		Downstream trap		Upstream trap		Downstream trap		Upstream trap	
Time period[1]	1939	1940	1939	1940	1939	1940	1939	1940	1939	1940	1939	19[illegible]
April 1-6	....	40	....	....	....	1	....	....	....	....	....	[illegible]
April 7-13	....	416	....	....	....	....	....	....	....	....	....	[illegible]
April 14-20	134	530	....	1	....	1	....	....	....	....	....	[illegible]
April 21-27	345	821	....	39	4	9	....	....	28	14	....	[illegible]
April 28-May 4	220	1,619	115	137	11	24	....	1	60	34	....	[illegible]
May 5-11	164	680	213	268	37	40	1	5	38	22	....	[illegible]
May 12-18	27	75	6	235	26	211	....	95	13	24	....	[illegible]
May 19-25	6	14	79	43	13	257	10	84	3	9	1	[illegible]
May 26-June 1	4	12	13	44	25	152	12	41	5	2	3	[illegible]
June 2-8	2	168	5	30	1	200	5	79	3	5	5	[illegible]
June 9-15	....	2	3	9	....	8	....	27	....	....	1	[illegible]
June 16-22	....	4	1	35	....	3	....	22	....	1	....	[illegible]
June 23-29	....	10	....	15	....	....	....	14	....	1	....	[illegible]
June 30-July 6	....	2	....	....	....	....	....	5	....	1	....	[illegible]
Total	902	4,393	435	856	117	906	28	373	150	113	10	[illegible]

[1]In 1939 the weir was in operation from April 7 to June 19; the first fish were taken in the weir on Apr

in the downstream trap in 1940 were marked either by tagging or by fin-clipping, and 1,349 of the 1,355 upstream migrants were similarly marked (Table 3). Of the downstream migrants, 465 (8.3 per cent) returned through the upstream trap, and 355 (26.3 per cent) of the upstream migrants returned downstream. If it is assumed that the few fish which were not marked behaved similarly to the marked fish, the total loss of fish to the lake (and gain to the stream) may be estimated at 4,136 fish during the period of operation of the weir.

Because the bulk of the run was composed of suckers and redhorse, the loss to the lake of game fish was not large. Only 37 of the 163 northern pike and yellow pikeperch (numbers of the two species combined) that left Houghton Lake returned through the weir again. This net loss to Houghton Lake of 126 fish was reduced by the 52 of the 54 upstream migrants that did not return downstream again. The net loss to Houghton Lake of these two species was therefore 74 fish, or 44.7 per cent of the original 163 fish.

Doubtless some of all of the species taken in the weir were normal residents of the river. The first upstream migrants of all species in 1940 were presumed to be inhabitants of the river since they were unmarked fish. Whereas the downstream migration was mainly a spawning run, the upstream run was composed mainly of spent fish. It is possible that many of the downstream migrants found suitable habitats and remained in the river. Conditions for fish were favorable in the river. Food for all species was plentiful. Shelter was adequate for young and adults of all species. All species were observed to spawn in the river, with the possible exception of the yellow pikeperch.

It is known that many fish, especially suckers and redhorse, die after spawning. In 1939, and 1940, a number of dead fish were found

...h taken in the Muskegon River Weir in 1939 and 1940*

Northern pike				Yellow pikeperch				Other species				Total (all species)			
Downstream trap		Upstream trap		Downstream trap		Upstream trap		Downstream trap		Upstream trap		Downstream Trap		Upstream Trap	
1939	1940	1939	1940	1939	1940	1939	1940	1939	1940	1939	1940	1939	1940	1939	1940
[illegible]	10	....	....	....	....	....	....	....	....	....	....	....	51	....	....
[illegible]	52	....	....	....	6	....	....	....	....	....	....	....	474	....	....
[illegible]	33	....	2	5	8	....	....	....	....	....	....	143	572	....	3
[illegible]	17	....	6	6	3	....	1	1	1	....	....	389	865	....	46
[illegible]	9	14	13	1	1	....	....	....	4	....	1	295	1,691	129	154
[illegible]	11	1	4	1	1	....	....	3	2	....	....	244	756	215	292
[illegible]	4	....	13	3	1	....	1	2	1	....	....	71	316	6	347
[illegible]	4	1	5	....	....	....	....	1	1	....	1	23	285	91	133
[illegible]	....	....	1	....	1	....	....	....	2	....	1	34	169	28	91
[illegible]	....	....	1	....	....	....	1	3	1	1	....	9	374	16	118
[illegible]	....	....	....	....	....	....	....	3	9	....	....	3	19	4	56
[illegible]	....	....	3	....	....	....	1	....	5	....	2	....	13	1	69
[illegible]	....	....	....	....	2	....	....	....	1	....	1	....	14	....	31
[illegible]	....	....	....	....	....	....	2	....	....	....	....	....	3	....	15
[illegible]	140	16	48	16	23	0	6	13	27	1	6	1,211	5,602	490	1,355

In 1940 the weir was operated from March 31 to July 11.

TABLE 3.—*The number and percentage of marked fish that were recovered in the Muskegon River weir in 1940*

Species	Total number of fish marked (downstream trap)	Return of marked fish upstream	Percentage of returns	Total number of fish marked (upstream trap)	Return of marked fish downstream	Percentage of returns
Common sucker	4,393	278	6.3	856	300	35.0
Northern redhorse	906	107	11.8	373	51	13.7
Northern pike	140	33	23.6	48	2	4.2
Dogfish	113	43	38.1	66	2	3.0
Yellow pikeperch	23	4	17.4	6	0	0.0
Totals	5,575	465	8.3	1,349	355	26.3

TABLE 4.—*Number of fish found dead above or lodged against the Muskegon River weir in 1939 and 1940*

Species	Number of fish		Total
	1939	1940	
Northern redhorse	289	77	366
Common sucker	7	65	72
Bullhead	19	11	30
Pumpkinseed sunfish	2	9	11
Yellow pikeperch	5	2	7
Bluegill	....	6	6
Smallmouth black bass	2	4	6
Rock bass	2	2	4
Northern pike	....	3	3
Dogfish	....	2	2
Black crappie	....	1	1
Rainbow trout	....	1	1
Total	326	183	509

above the weir, and others floated down to and lodged against the weir (Table 4). Redhorse and suckers were observed to spawn above the weir, and many of these species were found dead against the weir immediately after spawning activity was noted. The number of fish that died below the weir is not known, but there was undoubtedly some mortality due to spawning and other factors. This mortality may account in part for the relatively few recaptures of all species and especially of the suckers and redhorse.

Anglers were exceedingly active in the Muskegon River in the late spring and early summer of both 1939 and 1940. Many northern pike, suckers, redhorse and yellow pikeperch which normally would have returned to Houghton Lake were taken by fishermen.

Some of the migrants traveled downstream a considerable distance. For example, fin-clipped suckers were found spawning in Townline Creek, a tributary of the Muskegon River, 45 miles below the weir, and three tagged yellow pikeperch were recovered by anglers in the impoundment formed by the Big Rapids Dam, a distance of 132 miles below the weir.

Conclusions.—There is some migration of fish to and from Houghton Lake and the Muskegon River in the spring and early summer. The movement appears to be associated with spawning. Common suckers

and the redhorse together made up 92.5 per cent of the total number of upstream and downstream migrants in 1939 and 1940, while bowfin made up 3.9 per cent, northern pike 2.5 per cent, yellow pikeperch 0.5 per cent and all other species 0.6 per cent. Suckers and redhorse are seldom captured in Houghton Lake by anglers and are taken in the river only when spearing is permitted in the spring. Dogfish are seldom used as food and considerable agitation for the removal of this species is usually manifest by sportsmen's groups. Despite the fact that more northern pike and yellow pikeperch were taken in the weir in 1940 than in 1939, the numbers are insignificant. More northern pike ran up Peterson's ditch in 1939 and 1940 (Carbine, 1942) than ran down the Muskegon River. Peterson's is only one of perhaps a dozen spawning areas for northern pike at Houghton Lake. The northern pike run in the Muskegon River is therefore only a small percentage of the total run from the lake. The Muskegon River produces good northern pike fishing. From the small number taken in the weir we might assume that few yellow pikeperch leave Houghton Lake to spawn in the river. The yellow pikeperch population in this part of the Muskegon River was probably small as indicated by the small catch of this species made by anglers.

There are sufficient numbers of northern pike, rock bass, perch, and other species in the Muskegon River to form an adequate breeding stock for the impoundment formed by the Reedsburg Dam. From present indications, northern pike should do well in this impoundment because the habitat is ideal for this species. The weir records indicate that Houghton Lake will not contribute much to the new impoundment in the way of fish except suckers and redhorse. Before the construction of the Reedsburg Dam, at least 24.2 per cent of the 153 northern pike that left Houghton Lake to spawn in the river in 1939 and 1940 returned again to Houghton Lake. Of course, each year some fish undoubtedly find conditions to their liking in the river and never return to the lake. Also, there might now be an upstream spawning run of northern pike from the new impoundment that enter Houghton Lake and remain there. The only way to determine whether such a movement of northern pike into the lake is occurring would be to reinstall the weir in the river between Houghton Lake and the impoundment.

Whether or not the Reedsburg Dam would block the migration of fishes in the Muskegon River presents a problem that is of great concern to the Houghton Lake Chamber of Commerce. The dam was provided with a fish ladder, but its effectiveness is questionable. From the operation of the weir, and the results of tagging experiments, we know that a considerable number of suckers and a few northern pike and yellow pikeperch travel downstream—some farther than the dam.

The return of part of the downstream migrants to Houghton Lake may be prevented by the Reedsburg Dam. We are of the opinion that even though the fish ladder is not too successful, little difference in the fish populations of Houghton Lake and the new impoundment will result whether or not the fish are able to get over the dam.

The Lake Gogebic Weir

Prompted by a succession of poor fishing seasons, especially from 1936 to 1939, interested groups began to search for a solution to the problem of improving fishing in Gogebic Lake (Gogebic and Ontonagon Counties), the largest inland lake (14,780 acres) in Michigan's Upper Peninsula. Sportsmen and resort operators contended that larger numbers of yellow pikeperch and other fish escaped each year down the Ontonagon River outlet and did not return to the lake. The basis for this belief was that fishing in the spring was good in the channel between Gogebic Lake and the outlet dam and in the river below the dam. Sentiment for the prevention of the supposed migration increased until several petitions had been circulated and the County Board of Supervisors formally requested the Department of Conservation to install an electric fence across the lake outlet. Instead of complying with this request the Department directed its Institute to determine the nature and extent of fish movement at this point.

A weir was installed in the Ontonagon River about one-half mile below the lake proper but just above the Bergland Dam of the Copper District Power Company. At this point the depth of the river ranges from 6 to 9 feet and the width from 130 to 145 feet, according to the water level. The weir was in operation from April 10, 1940, until September 14, 1941.

Description of weir.—The weir crossed the Ontonagon River at right angles to the banks. This method of construction was not the most desirable or the most efficient, but was the only one that could be used in the location available. The details of construction were similar to those described by Shetter (1938) for the Canada Creek weir. Bars of ⅝-inch reinforcing iron placed in a frame at 2-inch intervals left openings of 1⅜ inches. The total cost of the weir including materials, labor (furnished in part by the C.C.C. Camp Gogebic of the Ottawa National Forest) and transportation expenses was $676.05. The reinforcing iron which alone cost $352.50 was recovered and used in construction work when the weir was dismantled.

Results.—The traps were checked at least twice a day during the principal run of fish and at least three times a week during the remainder of the period of operation. There were two periods when the structure was not effective due to breaks caused by high water and debris.

Only eight species of fish were taken in the Gogebic weir (Table 5).

TABLE 5.—*Total catch and the size range of each species taken in the Lake Gogebic weir between April 10, 1940, and September 14, 1941, both dates inclusive. For scientific names, refer to Tables 1 and 7*

Common name	Number of fish captured			Total length (inches)		
	Down-stream trap	Up-stream trap	Total	Mini-mum	Aver-age	Maxi-mum
Common sucker	420	169	589	....	....	....
Yellow pikeperch	56	53	109	12.4	17.0	27.7
Rock bass	13	59	72	6.4	8.9	11.4
Northern pike	14	14	28	15.6	18.0	29.7
Black crappie	7	2	9	11.9	13.5	14.1
Yellow perch	2	6	8	8.2	10.5	12.0
Smallmouth black bass	4	2	6	14.0	16.6	20.2
Largemouth black bass	1	0	1	....	....	....
Total	517	305	822	....	....	....

TABLE 6.—*Weekly catch of the most important species of fish taken in the Lake Gogebic weir, 1940 and 1941*

Time pe.iod	Common sucker		Yellow pikeperch		Rock bass		Northern pike	
	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
1940								
April 14-20	....	....	....	....	....	....	....	1
April 21-27	34	100	11	8	....	....	3	6
Ap.il 28-May 4	43	304	2	9	1	....	1	....
May 5-11	10	1	....	28	....	1	....	....
May 12-18	32	6	2	2	....	1	....	....
May 19-25	2	1	....	5	....	1	....	....
May 26-June 1	....	1	....	....	....	....	....	....
June 2-8	9	1	1	....	....	3	....	1
June 9-15	13	1	2	2	9	2	....	....
June 16-22	2	....	....	1	11	3	....	....
June 23-29	....	....	....	....	7	2	....	....
June 30-July 6	2	....	....	....	10	....	....	....
July 7-13	1	....	5	....	6	....	1	....
July 14-20	5	....	2	....	3	....	3	....
July 21-27	1	....	3	....	3	....	1	....
July 28-Aug. 3	4	....	1	....	....	....	....	....
Aug. 4-10	....	....	1	....	2	....	....	....
Aug. 18-24	5	1	1	....	1	....	....	....
Aug. 25-31	....	1	3	....	1	....	....	....
Sept. 1-7	....	....	8	....	1	....	....	....
Sept. 8-14	....	....	2	....	....	....	....	1
Oct. 6-12	....	....	1	....	....	....	....	....
Oct. 20-26	....	....	....	1	....	....	....	....
Oct. 27-Nov. 2	....	....	....	....	....	....	....	1
Nov. 10-16	....	....	....	....	....	....	1	1
1941								
April 6-12	....	....	....	....	....	....	....	1
April 13-19	1	....	1	....	....	....	....	1
April 19-26	....	....	....	....	....	....	....	1
April 27-May 3	1	1	....	....	....	....	....	....
May 4-10	....	2	....	....	....	....	....	....
May 11-17	2	....	....	....	1	....	....	....
May 18-24	1	....	1	....	1	....	....	....
May 25-31	....	....	1	....	1	....	....	....
June 15-21	....	....	....	....	....	....	1	....
June 22-28	....	....	....	....	....	....	2	....
June 29-July 5	....	....	....	....	....	....	1	....
July 6-12	1	....	....	....	1	....	....	....
July 20-26	....	....	5	....	....	....	....	....
Total	169	420	53	56	59	13	14	14

All yellow pikeperch and northern pike were "jaw-tagged," and the other species were marked by clipping fins. Different fins were clipped on upstream and downstream migrants to permit future identification of all fish which passed through the weir.

There is some upstream and downstream movement of fish in the outlet of Gogebic Lake during the period when the lake is not covered by ice (Table 6). The major movement occurs from mid-April to the end of June, which period covers the spawning season of most of the species taken. Suckers, yellow pikeperch, northern pike, and rock bass, in that order, were the species observed most frequently in the river at that time.

Except for the suckers, there was no significant loss of fish from Lake Gogebic by migration down the outlet. More game fish were counted going upstream than were counted going downstream during the period of operation of the weir.

Conclusions.—From the data obtained from the operation of the weir, it was determined that the erection of a fish screen for the prevention of fish movement out of Lake Gogebic would not benefit the fishery in that water.

The Platte River Weir

Occasionally during low water and following strong on-shore winds, temporary sand bars may develop across the mouth of the Platte River (Benzie County), where it enters Lake Michigan. It was believed by sportsmen that because of these bars, fish were not able to ascend the river. The Platte River is famous for its trout fishing, particularly for the big rainbow trout (steelheads) that enter the stream from Lake Michigan. Previous to the summer of 1941, many interested people agitated for stream-improvement devices, or for dredging or breakwater construction to remedy the situation created by these temporary sand bars. Since it was known that these types of improvement suggested were quite expensive, the Department of Conservation decided that it was first necessary to determine the nature and extent of the fish migration at this point and to what degree this migration was blocked by sand bars.

The site chosen for the weir was approximately 1½ miles upstream from Lake Michigan. It had the advantage of being state-owned and close to a county road. The width of the stream was 45 feet, and the depth at the time that the weir was installed was 29 inches.

Description of weir.—Construction of the weir was complicated by the fact that at certain times of the year there was considerable boat traffic between the upper river and Lake Michigan. The final design of the weir incorporated all of the best features of previous weirs used by the Institute, plus a pair of boat gates operated by pulleys and cranks.

The entire structure was placed on single-board sheet-piling driven from 3 to 5 feet into the bottom. This construction eliminated most of the undercutting usually experienced in weir operation. The original plans which called for triple Wakefield piling could not be used because of the difficulties encountered in driving the piling into the subsurface material of rubble and boulders. A double row of round pilings, at intervals of 5 feet, supported the framework that carried the blocking bars of the weir (Figs. 4 and 5). All piling was driven into the bottom with a power-driven pile-driver and a jet pump.

The diagram (Fig. 4) shows the most prominent features of the weir. A and B are the boat gates, each approximately 5 by 15 feet. C and D are the traps, downstream and upstream respectively, each 6 by 5 by 5 feet. Each trap has a board floor to eliminate any hiding places for fish. A funnel made of ½-inch, galvanized wire screen acts as an entrance for fish into each trap. E and F are the stationary blocking arms, both about 45 by 5 feet. The individual blocking bars were 1- by 2-inch slats, spaced 1½ inches apart. This spacing allowed all but the larger fish to pass through the structure without being trapped. The blocking bars on the Platte River weir were nailed directly to the framework, but it is possible to make these in frames so that a section of the blocking arm can be removed or replaced at any time. G is a 6-foot working platform. A catwalk on the downstream side of the blocking arms facilitates the cleaning and repair of the weir. H is a solid row of single-sheet piling, built as a safety measure in time of high water, across a 150-foot stretch of marsh to higher ground on the south side of the river. I is a sea wall to prevent erosion of the north bank. The blocking arms, traps, boat gates, and sea wall all rested on sheet-piling. J is the attendant's cabin.

Results.—The weir was in constant operation from November 1, 1941 until June 20, 1943, except for several brief periods when pressure from slush ice and snow broke the boat gates or made it necessary to leave the gates open.

In 1942 all upstream migrants were either "jaw-tagged" or marked by clipping fins. Tags were used on most rainbow trout and all northern pike. All other fish, including some rainbow trout, were "fin-clipped." In 1943, all suckers taken in the weir were distributed free to anyone possessing a current fishing license. Because of a shortage of help, only a few of the rainbow trout were marked in 1943.

A total of 14 species of fish were taken in the Platte River weir (Table 7). The numbers of the two species of suckers taken in the weir were recorded together. The rainbow trout and suckers made up 94.27 per cent of the catch; the remaining 5.73 per cent was divided among eleven species.

The heaviest run of all species combined occurred between April 1 and May 31 (Table 8). The spring upstream migration of rainbow

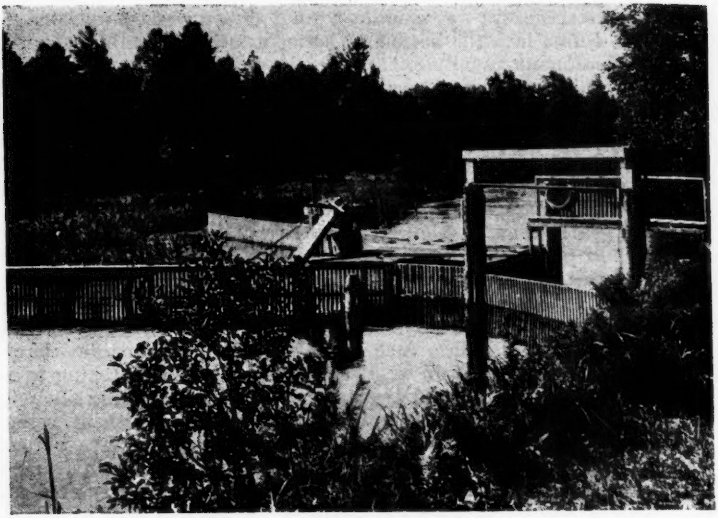

FIGURE 4.—View of the Platte River weir looking downstream. The movable boat gates are to the right. The upper boat gate is in place, and the lower gate has been raised. The chute to the left is used to return the fish moving upstream to the water after the required data are obtained. The traps are at the left of the boat gates.

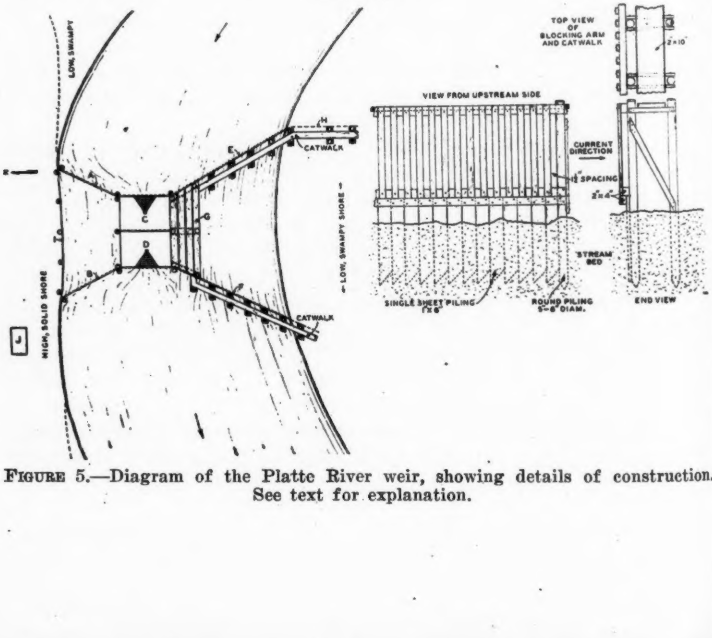

FIGURE 5.—Diagram of the Platte River weir, showing details of construction. See text for explanation.

TABLE 7.—*Total catch of each species taken in the Platte River weir between November 1, 1941, and June 20, 1943, both dates inclusive*

Common name	Scientific name	Number of fish captured: Upstream trap	Downstream trap	Total
Common sucker	*Catostomus c. commersonnii*	4,365	169	4,534
Sturgeon sucker	*Catostomus c. catostomus*			
Rainbow trout	*Salmo gairdnerii irideus*	965	97	1,062
Smelt	*Osmerus mordax*	216	1	217
Yellow perch	*Perca flavescens*	76	....	76
Rock bass	*Ambloplites r. rupestris*	13	....	13
Lake herring	*Leucichthys a. artedi*	12	....	12
Dogfish or bowfin	*Amia calva*	2	7	9
Northern pike	*Esox lucius*	2	2	4
Yellow pikeperch	*Stizostedion v. vitreum*	4	....	4
Bullhead	*Ameiurus* sp.	2	....	2
Smallmouth black bass	*Micropterus d. dolomieu*	1	....	1
Eastern burbot	*Lota lota maculosa*	1	....	1
Carp	*Cyprinus carpio*	1	....	1
Total		5,660	276	5,936

TABLE 8.—*The number of suckers and rainbow trout taken in the Platte River weir between November 1, 1941, and June 20, 1943, both dates inclusive. Time periods when no fish or very few fish were taken have been combined*

Time period	Suckers: Upstream trap	Suckers: Downstream trap	Rainbow trout: Upstream trap	Rainbow trout: Downstream trap
1941				
November, December	4	....	1	4
1942				
January, February	....	....	....	....
March-April 2	1	1	17	1
April 3-9	4	....	220	....
April 10-16	26	....	344	7
April 17-23	1,043	....	121	2
April 24-30	447	....	51	7
May 1-7	313	....	2	1
May 8-31	51	....	1	6
June-September	....	....	....	1
October 1-7	....	....	12	....
October 8-31	5	....	....	....
November, December	4	1	....	1
1943				
January-March	....	....	....	1
April 1-15	....	....	....	....
April 16-30	206	1	113	4
May 1-15	1.075	....	57	2
May 16-31	762	166	18	59
June 1-20	424	....	8	1
Total	4[illegible]5	169	965	97

trout extended from March 25 to May 10 in 1942, and from April 19 to June 14 in 1943. Weather conditions are probably responsible for the difference in the time of the run each year. In 1942, 756 mature rainbow trout were passed upstream through the weir and in 1943 only 196. Possible reasons for this difference may have been: (a) passage of fish through holes in the sheet-piling (H) or when the boat-slip was open in the early winter of 1943 because of slush ice; (b) a smaller run of fish in 1943; and (c) discouragement of fish from running in 1943 by opening-day anglers. In 1942 and 1943, before starting their upstream migration, between 500 and 800 large adult rainbow trout entered and stayed in the river between the weir and Lake

Michigan from mid-November until the following spring. In 1942 the heavy run started on April 5 and the majority had been dipped over the weir by the time the fishing season opened on April 25. In 1943 the run was delayed by cold weather and the fish did not begin to move upstream until April 19. Anglers fished over heavy concentrations of rainbow trout below the weir when the fishing season opened on April 24. Observations indicated that this angling activity frightened the fish to such an extent that the majority of them returned to Lake Michigan.

From the data obtained from measurements of random samples, the length of the rainbow trout ranged from 17 to 34⅝ inches, and the weight varied from 2 to 18 pounds. Males averaged 26¼ inches in length and 7 pounds in weight, while females had an average length of 28⅛ inches and an average weight of 8.7 pounds.

The downstream movements of fish through the weir were confined chiefly to the spring spawning periods or following the spawning periods.

Conclusions.—During the 20 months that the weir was in operation, observations indicated that fish were able to enter the river at any time. Therefore, no improvements need be made in the channel of the river mouth, unless future observations indicate a change of conditions.[2] During the period of operation of the weir the depth of water in the main channel at the river mouth varied from 17 to 48 inches. The position of the river mouth changed noticeably. In 1943 the confluence of the river with Lake Michigan was approximately 700 feet west and somewhat south of its position in 1941.

ACKNOWLEDGMENTS

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[2]The Platte River weir will be operated during the spring of 1944 and perhaps in other years.

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AGE, GROWTH, SEXUAL MATURITY, AND POPULATION FLUCTUATIONS OF THE YELLOW PIKE-PERCH, *STIZOSTEDION VITREUM VITREUM* (MITCHILL), WITH REFERENCE TO THE COMMERCIAL FISHERIES, LAKE OF THE WOODS, MINNESOTA[1]

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ABSTRACT

The scale method of growth analysis is applicable to the pike-perch of Lake of the Woods, but the body-scale relationship is that of a third-degree polynomial rather than a straight line. Length calculations were made using the corrected body-scale relationship. Female pike-perch grow more rapidly than the males, but the differences in growth rate are small. Lee's phenomenon is pronounced and is apparently due to the selective removal of the faster growing fishes by the commercial fisheries. The growth rate is more rapid during years with high mean summer temperatures, July temperatures being most significant. The weight increases approximately as the standard length raised to the 3.1 power. Male pike-perch mature when 4 years old, but females usually do not mature until 5 or 6 years of age.

Fluctuations in the abundance of pike-perch are quite pronounced. There is a suggestion of a 10-year cycle of abundance in the commercial catch. The fluctuations are associated with differences in the strength of various year classes, but the causes of these differences are not evident at present. Fry planting has no apparent effect on the strength of the year classes or the subsequent commercial catch. Depletion of pike-perch is indicated by the rapid decline in the catch from 1935 to 1939. The depletion is probably due to the destruction of spawning beds by pulp mill wastes and to an excessive drain on the fishery. It is believed that an increase in the size limit would increase the total catch and would provide a more adequate spawning stock. It is also suggested that fishing practices be changed so that saugers and perch may be removed from the lake in proportion to their abundance. At the present time the survival of these two species is favored over the survival of pike-perch.

INTRODUCTION

Fishery management is handicapped by the lack of information on the life history, growth rates, population fluctuations, and ecology of the fish. Information of this kind is often not available even for fish as important and as common as the yellow pike-perch or walleye, *Stizostedion vitreum vitreum* (Mitchill). Miscellaneous growth-rate data are available for the pike-perch in certain waters (Adamstone, 1922; Hart, 1928; Deason, 1933, MS.; Eddy and Carlander, 1939, MS.; Lindeborg, 1941; Schloemer and Lorch, 1942). No critical analysis of the scale method as applied to the pike-perch has been published, but Deason's (MS.) study of the Lake Erie pike-perches denoted that the

[1]The material in this paper represents part of a thesis presented to the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

scale method was applicable to all three representatives of *Stizostedion*. Even where the growth rate has been studied, little is known of the factors which control or modify fish growth. The causes of change in the abundance of fresh-water fish and the effects of various management and fisheries practices are only partially known. Additional information on these problems makes possible more efficient fisheries management.

A fishery investigation on Lake of the Woods initiated in 1939 by the Minnesota Department of Conservation and the University of Minnesota and now being continued by the Department's Bureau of Fisheries Research presented an opportunity to study some of these problems. Lake of the Woods, on the boundary between Minnesota and Canada, was investigated because it supports an important commercial and sport fishery. Recent declines in annual production of pike-perch, one of the most important species, indicate that changes in management may be necessary to prevent depletion. Although all species were studied during the investigation, only the data on pike-perch are summarized in this paper.

Body-Scale Relationship and Computation of Growth Rate

In previous investigations, the growth rates of the pike-perch have been computed on the assumption that the growth in length of the fish is directly proportional to the growth of the anterior radius of the scale. Schloemer and Lorch (1942) use the straight line relationship on the basis of unpublished proof of its validity. In the present study, this assumption was tested and found to be inaccurate for pike-perch from Lake of the Woods. The relationship between the anterior scale radius and the standard length[2] of the Lake of the Woods pike-perch was determined from measurements of 4,455 scales from fish 50 to 660 millimeters long (Figure 1). These scales were taken near the lateral line, immediately above the posterior edge of the pectoral fin. The use of "key" scales, as recommended by Hile (1941) and others, would have reduced the amount of variation in scale size, but a satisfactory curve was derived with non-key scales by increasing the size of the sample. It is apparent that the scale radius is not directly propor-

FIGURE 1.—Body-scale relationship of yellow pike-perch from Lake of the Woods.

tional to the body length of the pike-perch. The following formula for the relationship between the scale radius and the body length was calculated by the method of averages:

[2]All fish were measured while still fresh. Standard lengths were recorded for each fish and all measurements are given as standard lengths in this report. Because fork, and total lengths are used in the commercial fisheries, it was necessary to determine the mathematical relationship between the various methods of measurement. Application of Woo's test of rectilinearity (Treloar, 1936) proved that these relationships are not strictly straight lines, but computation of the nearest straight lines, by the methods of least squares, afforded sufficiently accurate descriptions of the relationships and indicated that the conversions from one form of measurement could be made as follows:

Fork length = 1.104 standard lengths.
Total length = 1.159 standard lengths.
Total length = 1.050 fork lengths.

These conversions were based on measurements of 3030 Lake of the Woods pike-perch.

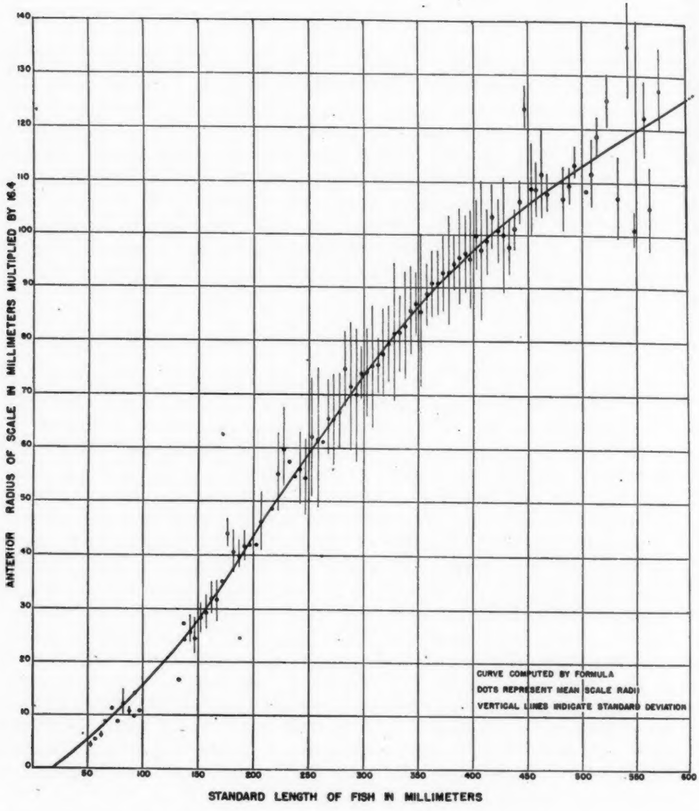

FIGURE 1.—Body-scale relationship of yellow pike-perch from Lake of the Woods.

$$L = 18.958 \text{ millimeters} + 5.887R - 0.0538\,R^2 + 0.000349R^3,$$

where L = standard length in millimeters,

and R = anterior scale radius in millimeters ($\times$ 16.4).

This formula results in a curve that describes the body-scale relationship of the pike-perch from Lake of the Woods. It is used in the method described by Hile (1941) for the computation of all growth rates. Growth computations based on this curve gave lengths which were 30 per cent higher at the end of the first year of life than lengths computed on a direct proportion basis. At the end of the second, third, fourth, fifth, sixth, and seventh years of life, the lengths based on the curve were 10 per cent greater, 1 per cent greater, 2 per cent smaller, 4 per cent smaller, 4 per cent smaller, and 3 per cent smaller, respectively, than lengths based on direct proportion. Comparison with actual lengths of the pike-perch in various age groups at time of capture indicated that the lengths based on the corrected body-scale relationship were more accurate than those based on direct proportion.

The validity of the annulus as a year mark was tested by methods similar to those used by Van Oosten (1929) and Hile (1941), and the annulus was found to be a satisfactory mark for assessment of age. Scales collected at various times during the growing season indicate that the annulus is formed in May or early June.

Age and Rate of Growth

It is usually assumed that sound fishery management cannot be developed without a knowledge of the fish growth rates. Scales were collected for growth-rate studies from 4,060 pike-perch in 1936, 1937, 1939, 1940, and 1941, at Lake of the Woods. To secure fish samples representative of the fish population and of the catch, fish were taken in minnow seines, gill nets with a variety of mesh sizes, pound nets, from the fishery stations, and anglers' creels.

TABLE 1.—*Average calculated standard lengths of pike-perch in each age group collected at Lake of the Woods, 1936 to 1941*

Age Group[1]	Number of Individuals	Standard length in millimeters at each annulus													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
I	23	132	....	....	....	....	....	....	....	....	....	....	....	....	....
II	93	149	213	....	....	....	....	....	....	....	....	....	....	....	....
III	454	151	217	268	....	....	....	....	....	....	....	....	....	....	....
IV	925	146	210	262	309	....	....	....	....	....	....	....	....	....	....
V	917	134	193	241	285	325	....	....	....	....	....	....	....	....	....
VI	351	137	197	245	288	329	368	....	....	....	....	....	....	....	....
VII	89	135	192	239	283	324	362	400	....	....	....	....	....	....	....
VIII	23	136	195	240	283	323	364	405	444	....	....	....	....	....	....
IX	12	135	192	237	275	321	364	409	449	487	....	....	....	....	....
X	5	137	190	233	270	308	349	391	435	478	515	....	....	....	....
XI	3	136	186	230	272	312	347	389	425	468	511	553	....	....	....
XIII	2	123	177	219	257	290	326	362	395	433	469	510	545	581	....
XIV	1	129	181	220	253	285	311	342	372	401	432	467	506	537	580
Grand Average (2,898 fish)		141	203	253	295	326	366	400	437	474	498	524	532	566	580
Standard deviation		12	11	11	13	18	23	21	22	36	37	53	38	46	....
Average annual increment		141	62	50	45	40	39	39	39	39	38	40	36	34	43
Growth based on summation of increments		141	203	253	298	338	377	416	455	494	532	572	608	642	685

[1]Several year classes are combined in each age group since collections were made over a period of 6 years. Sexes are also combined.

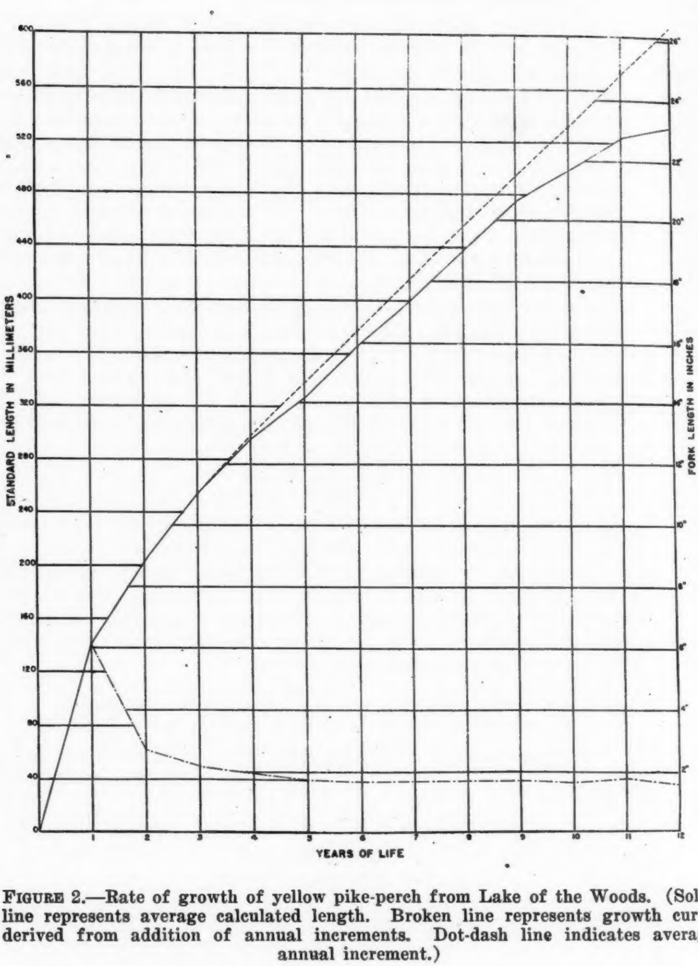

FIGURE 2.—Rate of growth of yellow pike-perch from Lake of the Woods. (Solid line represents average calculated length. Broken line represents growth curve derived from addition of annual increments. Dot-dash line indicates average annual increment.)

The most rapid growth in length occurs during the first year of life and the annual increments decrease each year until the fourth year, when the curve levels off (Table 1, Figure 2). Thereafter, the annual increment is about the same each year. The grand average calculated lengths of the fish at the time of formation of each annulus are usually considered to represent the average growth rate, but the summation of annual increments is more representative of actual growth conditions. The average annual increment was computed on a basis different from that employed in many earlier growth studies. Usually the average annual increment is computed merely by subtracting the average length at the end of the previous year from the length at the end of the year in question. This method is correct only if all fish are of the same age. In the present study, only those fish that had completed the year's growth were used in determining the average size at the beginning of the year.

Sexes were combined in most of the growth data discussed here because the commercial fish are shipped without being cut open and because a determination of the sex of pike-perch during the summer is difficult. The females grow more rapidly than the males after the third or fourth year, but the difference in growth rate is small and the general characteristics of the growth curves are similar (Table 2).

Lee's phenomenon of the apparent change in growth rate was evident in samples collected each calendar year, but the phenomenon is partially masked where data are combined (Table 1) because several year classes are then combined in each age class. Growth data for fish in the same year class but collected in different years showed a similar phenomenon, for the older the fish were at the time of capture, the smaller were the calculated lengths for the first few years of life. In none of the samples was Lee's phenomenon evident in fish less than 3 years old.

TABLE 2.—*Growth rates of male and female pike-perch collected at Lake of the Woods in December, 1941*
[Standard deviations are indicated in parentheses]

Age group and sex	Number examined	Average standard calculated length at each annulus					
		1	2	3	4	5	6
IV							
Males	66	148	213	266	313	....	....
		(8)	(10)	(17)	(11)		
Females	50	147	209	266	314	....	....
		(9)	(12)	(12)	(15)	....	....
V							
Males	79	141	202	251	293	334	....
		(7)	(8)	(10)	(10)	(12)	....
Females	71	143	205	255*	300*	343*	....
		(7)	(9)	(10)	(11)	(14)	....
VI							
Males	9	137	196	242	285	326	364
		(6)	(13)	(8)	(8)	(5)	(7)
Females	14	138	197	244	287	329	372
		(8)	(9)	(8)	(10)	(11)	(13)

*The difference between the average length of males and of females is statistically significant, by "Student's *t* test," only in the instances marked.

Several explanations for Lee's phenomenon have been discussed by various authors (Van Oosten, 1929, Hile, 1936). Selective sampling cannot be used as an explanation in the Lake of the Woods pike-perch data, for the phenomenon was evident in samples collected by each method. The 1941 experimental gill-net sample included over 300 pike-perch taken in nets with equal lengths of 1.5-, 2-, 2.5-, 3-, and 4-inch mesh, stretched measure. Size distribution of the pike-perch in these nets is so wide that little selectivity is evident in fish ranging from 150 to 430 millimeters standard length. No size selection should occur in the 3- to 6-year-old fish in this sample, and yet these age classes showed Lee's phenomenon.

Samples composed entirely of one sex showed Lee's phenomenon, and therefore, difference in the growth rates and longevity of the male and female pike-perch cannot be the cause.

In the present study, if Lee's phenomenon were due to inaccurate calculation of the body-scale relationship and did not occur in the population or in the sample, calculations based on the true relationship would give slower growth in the first 3 years and more rapid growth in later years. The true body-scale relationship would thus be more nearly a straight line than the relationship which was used. However, the growth rates of several samples were calculated on a straight line basis, and Lee's phenomenon was still pronounced.

Lee's phenomenon in the Lake of the Woods pike-perch appears to be associated with the fishery operations. It was pointed out that the phenomenon was not evident in fish less than 3 years old. Pike-perch first enter the commercial fisheries in numbers at 4 years of age, but only the faster growing 4-year-olds are large enough to be caught. As these fish are removed, the remaining 4-year-olds show a slower average growth than the 3-year-olds. This same process continues for the next 2 years, for the slower-growing fish are not of legal length until 6 years of age. Beyond the sixth year, Lee's phenomenon is not distinct but is still evident in some samples. Hile (1936), Eschmeyer (1938, 1939), Hoover (1939), and others have shown that the faster-growing fishes are usually shorter-lived than the slower-growing individuals, and that this correlation between growth rate and longevity may account for Lee's phenomenon among older fishes. In general, it appears that at Lake of the Woods, Lee's phenomenon is not due to selective sampling but rather to changes in the population brought about by selective fishing.

Annual Fluctuations in Growth Rate

The average annual increment varies from year to year, and similar fluctuations in the various calendar years are shown by the fish in different age classes (Table 3). By using the methods described by Hile (1941), the growth in the various calendar years may be evaluated with reference to the average annual growth (Table 4). Various factors may influence these fluctuations in the annual growth. At Lake

TABLE 3.—*Annual growth increments, in millimeters, of Lake of the Woods pike-perch in the 1926 to 1940 year classes, during the calendar years 1926-1940*

Year of Life	Increment of Growth in Calendar Year														
	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
14	....	....	....	....	....	....	....	....	....	....	....	....	....	....	43
13	....	....	....	....	....	....	....	....	....	....	....	....	45	31	27
12	....	....	....	....	....	....	....	....	....	....	....	44	39	26	....
11	....	....	....	....	....	....	....	....	....	....	53	35	45	....	33
10	....	....	....	....	....	....	....	....	....	40	31	44	36	36	....
9	....	....	....	....	....	....	....	....	42	29	41	42	41	24	44
8	....	....	....	....	....	....	....	35	30	40	43	38	39	43	40
7	....	....	....	....	....	....	42	31	36	41	46	43	39	37	37
6	....	....	....	....	....	38	26	36	40	36	43	40	39	37	39
5	....	....	....	....	36	32	39	40	44	44	45	40	41	41	42
4	....	....	....	38	33	44	38	39	46	47	44	46	46	44	48
3	....	....	42	39	46	44	46	51	51	49	50	45	49	52	56
2	....	49	52	54	51	57	65	63	61	61	63	63	63	67	64
1	127	129	132	142	135	136	132	137	142	144	146	148	153	146	135
Number of fish in each year class..	1	1	2	3	17	58	285	256	392	425	678	515	150	58	20

of the Woods, summer temperatures appear to be among the most important of these factors, for growth was more rapid during years with high summer temperatures. The mean temperatures in July were evidently most significant, for the coefficient of correlation, r, between the annual growth increment and July temperatures was higher than in any of the other correlations. The coefficient was 0.75 which is highly significant since such a value would occur by chance only once in a thousand times (Treloar, 1936). The mean August temperature was also significantly correlated with the rate of growth ($r = 0.53$, probability $= 0.042$). It is realized that fluctuations in air temperatures do not portray exactly the fluctuations in water temperatures, but water temperatures in a shallow lake like Lake of the Woods closely follow trends in the air temperature. Rounsefell and Dahlberg (1932) found that the water temperature of the ocean was closely correlated

TABLE 4.—*Comparison of the fluctuations in annual growth of pike-perch with mean monthly summer temperatures at Lake of the Woods, 1926 to 1941*

Year	Percentage deviation of growth from 1926-1940 average	Mean monthly temperatures[1] in degrees Fahrenheit			
		June	July	August	September
1926	—10.27	57	66	63	51
1927	— 8.71	62	64	61	57
1928	— 5.40	58	66	62	52
1929	— 1.50	61	67	65	52
1930	— 4.47	63	68	67	55
1931	— 0.56	67	68	65	60
1932	— 1.99	67	67	66	55
1933	+ 0.30	69	69	65	58
1934	+ 4.38	62	66	62	52
1935	+ 4.18	57	71	65	51
1936	+ 8.06	61	73	66	57
1937	+ 4.53	62	70	71	55
1938	+ 4.85	63	68	68	58
1939	— 2.73	62	69	66	55
1940	— 0.83	60	68	65	60

[1]These data are from the records of the U. S. Weather Bureau (Climatological Data for United States, Minnesota Section). The data from two stations, on Lake of the Woods, Warroad and Baudette, were averaged.

with the fluctuations in air temperature and Doan (1942) noted a similar correlation at Lake Erie. It was thought that the growth rate might be more closely correlated with the summation of the mean monthly temperatures above 40° F. or above 60° F. Significant correlations were found in both cases (respectively: $r = 0.55$, probability 0.033; and r 0.60, probability = 0.018), but these correlations were not as high as the correlations with the July temperatures. No correlation could be demonstrated between rate of growth and temperatures during the other months, length of growing season, precipitation during any period, or water levels.

Length-Weight Relationship

The length-weight relationship is a valuable indicator of the robustness of a fish and also is an important tool of fishery management. The size of fish which may most profitably be harvested depends, to some extent, upon the length-weight relationship. The mathematical relationship between standard length and weight of Lake of the Woods pike-perch (Table 5) can be described by the following formula, computed by the least squares method:

TABLE 5.—*The length-weight relationship and coefficient of condition,* K, *of Lake of the Woods pike-perch, October, 1942*

Standard length in millimeters	Number of fish	Actual weight in grams: Average	Actual weight in grams: Range	Calculated[1] weight in grams	Average K
150-169	5	53	40-60	54	1.200
170-189	2	101	92-110	78	1.520
190-209	4	102	96-107	107	1.315
210-229	1	118	....	144	1.204
230-249	2	189	176-202	189	1.409
250-269	2	239	228-250	242	1.352
270-289	5	315	272-392	305	1.444
290-309	10	383	341-438	378	1.423
310-329	18	496	405-598	461	1.480
330-349	57	612	416-740	557	1.554
350-369	108	692	566-884	664	1.501
370-389	84	792	688-944	786	1.463
390-409	41	882	720-1,012	921	1.403
410-429	16	965	885-1,080	1,071	1.365
430-449	8	1,307	1,120-1,660	1,238	1.523
450-469	3	1,324	1,296-1,350	1,420	1.415
470-489	1	1,322	....	1,518	1.273
530-549	1	2,000	....	2,203	1.343
Average........	368	....	....	....	1.470

[1]Calculated by the formula $W = 7.95 \times 10^{-6} L^{3.099}$.

$$W = 7.95 \times 10^{-6} L^{3.099}$$

where W = weight in grams

and L = standard length in millimeters.

This empirical formula approximates that of a cubic parabola but indicates that the weight increases as the standard length raised to the 3.1 power rather than the cube of the length. Higgins (1936), referring administratively to investigations in progress by H. J. Deason, reported that the Lake Erie pike-perch increased in weight as the standard length raised to the 3.15 power.

As an indicator of the relative plumpness of fish, a number of authors[3] have used the coefficient of condition, K, where

$$K = \frac{W\,10^5}{L^3}$$

if W = weight in grams and L = standard length in millimeters.

The average K for the Lake of the Woods pike-perch, 1.47, is slightly higher than the average, 1.446, reported for Trout Lake, Wisconsin (Schloemer and Lorch, 1942). In Lake of the Woods, the average K factor is higher for the pike-perch from 310 to 389 millimeters long than for smaller or larger individuals. Additional lenght-weight data, recorded to the nearest ounce rather than the nearest gram, which was collected at Lake of the Woods from 1939 to 1941 gave similar results.

Sex Ratios, Size and Age at Maturity, and Fecundity

Natural reproduction is dependent, among other things, upon the number of spawning adults, upon the sex ratio, and upon the number of eggs produced per female. Considerable difficulty was experienced in determining the sex of pike-perch during the summer months when the gonads were very small, and therefore, Table 6 is based only on data collected in December, 1941. The proportion of females to males increases as the age of the fish increases. Males evidently are shorter lived than the females.

Table 6.—*Sex ratio of pike-perch collected in gill nets at Lake of the Woods, December, 1941*

Age group	Number of Males	Number of Females	Females per 100 Males
III	0	3	....
IV	66	50	76
V	79	71	90
VI	9	14	156
VII	....	1	....
VIII	....	2	....
XI	....	1	....

Table 7.—*Numbers of mature and immature pike-perch in each size class collected at Lake of the Woods, December, 1941, and October, 1942*

Standard length in millimeters	Males		Percentage Mature	Females		Percentage Mature
	Immature	Mature		Immature	Mature	
Under 250	16	0	0	1	0	0
250-269	0	1	100	1	0	0
270-289	0	1	100	3	0	0
290-309	1	4	80	7	0	0
310-329	0	21	100	16	0	0
330-349	0	99	100	33	6	15
350-369	0	136	100	72	22	23
370-389	0	63	100	48	46	49
390-409	0	10	100	28	27	49
410-429	0	1	100	8	4	33
430-449	0	1	100	3	6	67
450-469	....	....	....	1	3	75
470-559	....	....	....	2	1	33

[3]Hile (1936) contains an excellent discussion.

Male pike-perch at Lake of the Woods mature when they are 250 to 300 millimeters in length (Table 7). Female pike-perch, on the other hand, do not mature until they are at least 330 millimeters in length and the majority are 380 millimeters in length before attaining maturity. Only 4 per cent of the 4-year-old females taken in December, 1941, were mature, whereas 98 per cent of the males were mature at this age. Of 68 five-year-old females, 33.8 per cent were mature, and of the 16 six-year-olds, 31.2 per cent were mature. It will be noted that several large females were recorded as immature. Further study is needed to determine whether these fish skip spawning seasons, are immature, or are sterile. Deason (1933) reported several large immature female pike-perch in Lake Erie.

The number of eggs produced by 9 female pike-perch for a single spawning season was computed by the water displacement method. Number of eggs per female increased from 35,000 to 137,000 as the size of the fish increased from 343 to 556 millimeters. The average was 50 eggs per gram of body-weight.

Fluctuations in Abundance

A knowledge of the rate of growth, of the length-weight relationship, of sex ratios, and of other life history data are essential in formulating fishery management programs. However, of even more immediate concern in fishery management is a knowledge of the abundance of the fish, of changes in abundance, and of the causes for these changes. Accurate information on fish abundance is very difficult to secure. It is usually necessary to depend on statistics furnished by the commercial fisheries. Such statistics are often incomplete or inaccurate, and even at best reflect the catch rather than the abundance of the fish. When other data are lacking, however, fishery statistics may give much needed information.

Fluctuations in the total annual production of pike-perch suggest a 10-year cycle of abundance (Table 8). The best catches were made in 1915, 1925, and 1935. These peaks were followed by sharp drops, with minimum production in 1916, 1928, and 1939. Increases in production were more gradual than the declines. The period covered by the statistics is too short to afford conclusive evidence of a cycle, but the present data are suggestive. Cycles of somewhat similar length are well-established in a number of upland game species and in some fish (Huntsman, 1931; Huntington, 1931; Higgins, 1937).

It is possible that the cyclic tendency in the Lake of the Woods pike-perch is due to changes in fishing intensity rather than changes in abundance. However, the cycle should be apparent in the catch of other important species if the fluctuations are due entirely to difference in fishing methods. No other species showed similar fluctuations.

It has been shown frequently that fluctuations in the abundance of fish are usually due to difference in the strength of various year classes.

TABLE 8.—*Annual commercial yield of pike-perch in Lake of the Woods from 1888 to 1941*[1]

Year	Catch in thousands of pounds		Year	Catch in thousands of ponds	
	Minnesota	Total		Minnesota	Total
1888	25	....[2]	1916	313	954
1889	75	....	1917	469	1,431
1890	120	....	1918	367	1,120
1891	200	....	1919	408	1,245
1892	300	336	1920	389	1,038
1893	400	480	1921	352	1,324
1894	405	495	1922	444	1,486
1895	471	594	1923	665	1,804
1896	300	400	1924	659	2,057
1897	137	217	1925	626	2,080
1898	92	212	1926	509	1,152
1899	125	257	1927	588	1,180
1900	100	170	1928	544	1,075
1901	130	229	1929	680	1,148
1902	150	309	1930	768	1,310
1903	225	312	1931	955	1,597
1904	170	296	1932	657	....
1905	173	304	1933	671	1,445
1906	129	222	1934	892	1,722
1907	193	323	1935	1,021	1,926
1908	403	580	1936	847	1,618
1909	175	355	1937	636	1,270
....	....	....	1938	363	1,011
1913	429	1,309	1939	332	....
1914	450	1,373	1940	521	....
1915	567	1,731	1941	643	....

[1]Statistics taken from published reports of Minnesota Department of Conservation, from the annual reports, "Fishery Industries of the United States," issued by the U. S. Bureau of Fisheries, and from Evermann and Latimer (1910).
[2]Blanks in the table indicate that no data are available.

The presence of a particular abundant or "dominant" year class may cause the fish to be abundant for a few years, and then the abundance drops until another dominant year class rises. Extremely poor year classes may cause the population to fall below normal. At Lake of the Woods a striking variation in the strength of year classes of pike-perch was noted.

Three-year-old pike-perch, the 1936 year class, was the most abundant age class in the 1939 pound net catch. As 4-year-olds, the same class again dominated the catch in 1940, and in 1941 this year class was more abundant than the 5-year-old fish had been during any other year. The relative abundance of the various year classes may be estimated by comparing the age composition of the 1939, 1940, and 1941

TABLE 9.—*Age group composition of pike-perch in pound net catches at Lake of the Woods, 1939 to 1941*

Age Group	Percentage of catch in each age group		
	1939 Catch	1940 Catch	1941 Catch
II	4.5	1.1	1.2
III	32.7	20.2	15.8
IV	19.9	48.2	39.1
V	25.4	20.2	29.1
VI	11.5	8.5	11.2
VII	2.8	1.4	2.8
VIII	1.6	0.3	0.3
IX	0.7	0.2	0.2
X	....	....	0.1

pound net catches (Table 9). According to these data, the 1936 year class was the most abundant.

The samples collected at the fishery station in the fall of 1935 and 1937 show another dominant year class. In the former year, 66.7 per cent of the pike-perch taken were 4-year-olds, and in the latter year, 76.1 per cent were 5-year-olds. These percentages indicate a dominance of the 1932 year class. By 1939, most of the 1932 year class had disappeared from the catch, and therefore, the dominance of this year class is not apparent in the 1939 to 1941 collections.

If the various year classes are arranged according to abundance, they would be approximately as follows, from most abundant to least abundant: 1936, 1937, 1932, 1934, 1931, 1935, 1933, 1938, 1939. No correlation between the abundance of pike-perch in various year classes and temperature, rainfall, or water levels could be demonstrated. The weakness of the 1938 and 1939 year classes suggested that a decline in the population is to be expected.

Pike-Perch Stocking in Relation to Population Fluctuations

The effect of artificial propagation on the abundance of fish has received much critical attention in recent years. Pike-perch fry have been planted in Lake of the Woods in varying numbers since 1926 in the belief that these plantings were helping to maintain the fish populations (Table 10). No correlation could be demonstrated between the abundance of the year classes and the number of fry planted during

Table 10.—*Relationship between the plantings of fry and the production of pike-perch in Lake of the Woods*

Year	Millions of fry planted			Rank of year class abundance	Catch in thousands of pounds 5 years later	
	Minnesota	Ontario	Total		Total	Minnesota
1926	0.8	....	0.8	....	1,597	955
1927	....	59.7	59.7	....	....	625
1928	2.0	22.6	24.6	....	1,445	671
1929	7.9	65.0	72.9	....	1,722	892
1930	6.4	53.2	59.6	....	1,926	1,021
1931	6.4	39.0	45.4	5	1,617	847
1932	6.4	56.9	63.3	2	1,270	636
1933	6.4	42.3	48.7	7	1,014	363
1934	6.0	42.3	48.3	4	....	332
1935	20.0	26.0	46.0	6	....	521
1936	6.5	18.2	24.7	1	....	644
1937	1.5	43.0	44.5	3	....	....
1938	4.5	22.2	26.7	8	....	....
1939	16.9	29.0	45.9	9	....	....
1940	77.4	58.2	135.6	....	....	....

these years. From 24 to 63 million pike-perch fry were planted annually during the period from 1931 to 1939. In 1936, the smallest number was planted and yet this is the year that produced the most abundant year class. Similar lack of correlation between the number of fry planted and the abundance of pike-perch was evident in other years.

The 5-year-old pike-perch are usually the most important in the commercial catch at Lake of the Woods. If fry planting had any demonstrable effect on the numbers of fish, the commercial catch 5 years later should show fluctuations similar to the fluctuations in the number of fry planted. No such correlation could be detected. It is therefore evident that the planting of pike-perch fry in Lake of the Woods has little or no effect on the maintenance of the fishery.

This is not the first time that the ineffectiveness of fry planting in large lakes has been demonstrated. The planting of pike-perch fry was shown to be ineffective in Red Lake (Van Oosten and Deason, MS.), in Lake Huron, and in Lake Michigan (Hile, 1937). Van Oosten (1937, 1942) could find no evidence of relationship between the number of whitefish fry planted and the commercial catch in the Great Lakes.

Evidence of Depletion

Among the problems dealing with the abundance of fish, one of the most important to fisheries management is the effect of the fishery operations. The numbers of fish taken annually by a fishery can be controlled whereas many of the other factors are not subject to control. The annual catch may influence the abundance of the fish not only by actual removal of part of the population but also by depletion of the spawning stock. To maintain a high sustained yield it is important to detect downward trends in the population as soon as possible. There is evidence of a marked decline in the pike-perch population of Lake of the Woods in recent years.

The largest annual yield of pike-perch to the Minnesota fishermen was in 1935, but the total catch on the lake as a whole was less in 1935 than in 1925. From 1930 to 1939 the total catch was less than that from 1920 to 1929. Furthermore, the rapid decline in the catch following 1935 suggests depletion, for the decline was sharper than after any of the other peaks, and the annual catch fell lower in 1939 than at any time in the last two decades.

If the fluctuations are not of a cyclic nature, the statistics of the last few years are the principal ones to be used for interpreting trends, and then the declining catch following 1935 takes on even graver significance. The increased catches of 1940 and 1941 may indicate an upward trend, but the greater yield was almost entirely due to the gill-net catch (Table 11) which rose from 1,969 pounds in 1939 to 5,588 pounds in 1941.[4] This increased catch does not indicate a correspondingly large increase in the pike-perch population In 1940 to 1941 much deeper gill nets were used than in previous years. Prior to this time very few of the fishermen used gill nets over 30 meshes (about 8 feet) deep, but during 1940 and 1941 most of the nets were 50 meshes in depth and some were 80 meshes deep. There was thus

[4]It is recognized that catch per net is not an entirely satisfactory measure of abundance (Ricker, 1940), but it is the best that is available with the present data.

about a 60 per cent increase in the amount of webbing used per 1,000 linear feet of gill net. With this added webbing, the catch per 1,000 feet of gill net in 1940 and 1941 was only 30 per cent greater than the 1931 to 1939 average. During 1940 and 1941 another change in gill-net methods took place. The gill nets were floated in the surface waters where pike-perch were taken in large numbers. This is the first time, at least in recent years, that gill nets have been consistently

TABLE 11.—*Average annual catch of pike-perch in pounds per unit net, Minnesota portion of Lake of the Woods, 1932 to 1941*

Year	Per pound net	Per 1,000 linear feet of gill net
1932	4,065	2,634
1933	4,475	3,108
1934	4,694	4,785
1935	5,652	4,846
1936	4,162	4,875
1937	3,278	4,110
1938	2,459	2,024
1939	1,754	1,969
1940	2,699	3,617
1941	1,965	5,588

fished in this manner, and the change in fishing methods is undoubtedly responsible for much of the increased catch of pike-perch.

Further evidence that the increased catch does not indicate a proportionately large increase in the population is indicated by the annual catch of the pound nets (Table 11). The average annual yield per pound net declined from 1935 to 1939, increased slightly in 1940, but declined further in 1941.

There probably was an increase in the abundance of pike-perch in 1940 and 1941 over the low point in 1939. The pound-net catch was slightly greater, and the gill-net catch gained more than could be attributed to changes in gear. This increase was probably caused by the abundance of the 1936 year class. Even with this improvement in the population, there is evidence of depletion. As pointed out above, the increased population is less than the increased catch and although the population was greater than at the low point in 1939, it did not reach the 1932 to 1939 average. Furthermore, the poor strength of the 1938 and 1939 year classes indicates that the increase is a temporary one to be followed by further declines.

Causes of Depletion and Suggestion for Management

The depletion of the pike-perch in Lake of the Woods is probably due principally to two factors: destruction of important spawning beds in the Rainy River by pulp-mill wastes and to unwise fishing practices.

The Rainy River was formerly an important spawning area not only for the pike-perch but also for sturgeon and goldeyes (Evermann and Latimer, 1910). At the present time, and for several years past, these

spawning beds are buried under a blanket of pulp fiber. The sturgeon and the goldeyes are practically extinct and the present pike-perch population is probably the progeny of pike-perch spawning in the lake. Loss of the river spawning beds has probably had little bearing on changes in the fish population in recent years because the spawning beds were destroyed several years ago. The mills have been in action since 1907. Natural production of pike-perch is potentially limited by the loss of these spawning beds, however, and pollution should be abolished as soon as possible. It will take several years for the present pulp accumulation to disappear even when further pollution is discontinued. Because pollution has limited natural propagation, it is essential that special care be taken in management of the fishery to produce the highest possible yield.

The present size limit probably does not afford the pike-perch the protection needed to insure adequate breeding stock. It is generally held that a size limit should be set to afford a majority of the females an opportunity to spawn one or more times (Rawson, 1932; Fry, 1940). The majority of the female pike-perch at Lake of the Woods do not spawn until they are 380 millimeters in standard length, but they can be kept by the commercial fishermen after they reach a length of 345 millimeters (15 inches, fork length). All females must, therefore, escape one year of fishing before spawning. A minimum of 17 inches, total length, (373 millimeters, standard length) is needed to afford even half of the female pike-perch protection until they have spawned once. It is believed that such an increase in average size of the pike-perch taken commercially would increase the total annual production and at the same time provide a more adequate spawning stock.

It would also be advisable to promote the production of pike-perch by increasing the utilization and removal of fishes which normally compete with the pike-perch. At the present time, the fishing intensity is much heavier for pike-perch than for the other species. Maximum production can be more nearly secured if the other fish are removed in proportion to their abundance. Saugers, *Stizostedion canadense canadense* (Smith), comprise about 20 per cent of the adult fish population of the lake but only 7 per cent of the commercial catch. A similar situation occurs in the perch, *Perca flavescens* (Mitchill). Changing of fishing practices to permit a greater utilization of these species would help to keep these populations in check and would permit the establishment of a species balance more favorable to the pike-perch. Application of these suggestions should result in increased yields to the commercial fishermen, and at the same time safeguard the future supply of pike-perch in Lake of the Woods.

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SURVIVAL OF SEVEN- TO TEN-INCH PLANTED TROUT IN TWO MINNESOTA STREAMS

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ABSTRACT

Jaw-tagged 7- to 10-inch brook trout and brown trout were placed in two Minnesota streams to determine their survival. A creel census conducted on Duschee Creek showed that trout were returned at the rate of 1.49 and 1.55 fish per hour in succeeding seasons. Brown trout planted in this stream in the fall and spring yielded returns of 21.7 per cent and 28.0 per cent respectively, but no brook trout and only 2.0 per cent of the brown trout planted in summer were caught the following year. Planted trout contributed 8.8 per cent and 22.7 per cent of the total catch in successive seasons.

Catchable-sized brown trout and brook trout planted in the Knife River in the fall and in the spring showed a total return of 1.9 per cent from fall planting and 14.1 per cent from spring planting. Two and four-tenths per cent of the brook trout and 1.4 per cent of the brown trout planted in the fall and 19.6 per cent of the brook trout and 8.6 per cent of the brown trout planted in the spring were recaptured. The contribution of planted fish to the total catch in the Knife River was 23.0 per cent. The studies indicated that in the streams studied fall-planted brown trout may have survival comparable to that of spring-planted fish, that the majority of planted fish recovered are taken the first 3 to 4 weeks of the season, and that planted fish contribute only a minor portion of the total catch.

INTRODUCTION

Many experiments in trout-stream management have indicated that spring and open-season stocking of catchable-sized fish is more successful than fall or late-summer introductions (Hoover and Johnson, 1938; Shetter and Hazzard, 1941; Smith, 1941; Holloway and Chamberlain, 1942; Gee, 1942). The present studies were undertaken to test the applicability of generally approved methods to Minnesota streams. Since one of the experiments gave results quite unlike those reported from other areas, a brief discussion of local observations is presented here.

Two streams of widely varying type were selected for stocking experiments. Duschee Creek, a small tributary of the Root River in southeastern Minnesota, flows through a deep valley surrounded by limestone hills. The rich lands on the hills and in the lowlands are, for the most part, tilled or used for pasturage. From the headwater spring to its mouth the stream flows with a moderate gradient through a well defined channel cut 6 to 15 feet through heavy water-deposited material and the limestone substrata. Except for sharp floods caused by rainstorms, a constant flow of water is maintained largely by three springs whose flows range from 2,000 to 6,000 gallons per minute.

These large springs, together with the many small feeders, prevent the formation of a thick ice cover and keep the stream open during most of the winter.

The Knife River in the southern portion of the Lake Superior North Shore watershed is a larger stream which flows rapidly from its source in the highland plateau to Lake Superior. Its rugged channel traverses 17.5 miles of partially reforested timberland which is occasionally broken by small farm plots. Water stages and volume of flow are extremely variable since most of the water is derived from swamps and surface runoff. Heavy ice is formed in winter and high water temperatures occasionally occur in summer. The Knife River is moderately fertile and has a boulder and gravel bed. Its carrying capacity was recently improved by the creation of many new pools, shelters, riffle areas, and additional shade.

Brown trout, *Salmo trutta fario* L., and brook trout, *Salvelinus fontinalis fontinalis* (Mitchill) varying from 7 to 10 inches in length were marked with Monel-metal jaw-tags in the manner described by Shetter (1936) and planted in both streams. Their survival and influence upon subsequent catches were checked by means of a creel census.

Duschee Creek

On July 10, 1942, 500 brook trout and 500 brown trout were marked, held for 6 days in the hatchery, and on July 17 released in Duschee Creek. Following this planting there was a severe rain-flood which put the stream out of its banks and filled the water with silt. After the flood subsided, 14 brown trout and 5 brook trout were found dead by the census clerk. However, no further mortality was observed during the season. On November 18, 1942, 1,000 brown trout were marked and 6 days later were placed in the stream. The following spring, on April 16, 500 brook trout and 500 brown trout were marked and the brook trout planted in the creek. Fourteen days later, on April 30, the remaining fish were released. In the planting of fish, care was taken to distribute them throughout the stream and all possible precautions were taken to insure acclimatization of the hatchery fish. Subsequent to the summer planting of 1942 and during the entire season of 1943, a complete creel census was maintained on the stream.

Creel census.—The results of two seasons of creel census indicate that the fishing load in Duschee Creek was moderate but that the average catch per hour of fishing effort was greater than has been reported for many streams in other areas. In 1942, from July 17 to September 1, 173 anglers, fishing an average of 3.2 hours each, caught 672 brown trout, 69 brook trout, and 92 rainbow trout, or a total of 833 fish at an average rate of 1.49 fish per hour (Table 1). From May 1 to September 1, 1943, 659 anglers, each fishing an average of 3.5 hours, caught 2,418 brown trout, 549 brook trout, 456 rainbow trout, and 124 other fish, or a total of 3,547 fish at a rate of 1.55 fish per hour

(Table 2. During the 1942 season, the fishing intensity and the hourly rate of catch fell off steadily as the season progressed; but throughout the 1943 season, although the rate of catch varied considerably, there was no definite trend. The fishing load was heavy early in the 1943 season (42.0 per cent of the total annual catch was taken during the first 2 days) but declined after July 4.

Recoveries of marked fish.—The relative recovery of plantings in different seasons varied from results of previous workers. Nesbit and Kitson (1937) found that the recovery of fall-planted fish was exceeded by that of spring-planted fish in a ratio of 5.1 to 1.0. Shetter and Hazzard (1941) showed that in Michigan streams 3.2 per cent of

TABLE 1.—*Summary of creel census on Duschee Creek, July 17-September 1, 1942*

Interval	Total number of fishermen	Total number of fish	Catch per hour	Percentage of marked fish in the catch	Number of trout taken		
					Brown	Brook	Rainbow
July 17-23	83	499	1.84	6.6	418	46	35
July 24-30	34	172	1.34	8.7	128	15	29
July 31-Aug. 6	23	67	1.00	14.9	56	5	6
Aug. 7-13	18	51	1.05	17.6	42	0	9
Aug. 14-20	8	22	0.89	9.1	11	1	10
Aug. 21-27	5	9	0.72	33.3	9	0	0
Aug. 28-Sept. 1	2	13	2.00	7.7	8	2	3
Entire season	173	833	1.49	8.8	672	69	92

TABLE 2.—*Summary of creel census on Duschee Creek, May 1-September 1, 1943*

Interval	Total number of fishermen	Total number of fish	Catch per hour	Percentage of marked fish in the catch	Number of trout and other fish taken			
					Brown	Brook	Rainbow	Others
May 1	232	1,298	1.63	19.5	823	199	191	85
May 2	65	193	0.95	32.1	121	21	23	28
May 3-9	37	144	1.27	27.1	100	32	12	0
May 10-16	27	141	1.53	24.8	110	16	15	0
May 17-23	22	109	1.66	36.7	75	21	13	0
May 24-30	27	175	1.64	12.8	129	17	26	3
May 31-June 6	49	267	1.38	7.5	172	40	53	2
June 7-13	19	83	1.30	12.0	59	8	16	0
June 14-20	37	184	1.24	5.4	131	41	12	0
June 21-27	19	166	2.37	11.4	109	38	19	0
June 28-July 4	34	202	1.64	3.1	161	16	19	6
July 5-11	19	119	1.80	1.7	94	18	7	0
July 12-18	19	110	2.00	0.9	88	9	13	0
July 19-25	14	105	2.06	0.9	81	10	14	0
July 26-Aug. 1	6	41	2.16	0.0	22	16	3	0
Aug. 2-8	7	37	1.37	10.8	27	9	1	0
Aug. 9-15	9	82	2.41	0.0	55	21	6	0
Aug. 16-22	8	38	2.24	0.0	30	3	5	0
Aug. 23-29	6	27	1.23	0.0	14	7	6	0
Aug. 30-Sept. 1	3	26	1.63	0.0	17	7	2	0
Entire season	659	3,547	1.55	14.5	2,418	549	456	124

fall-planted and 6.8 per cent of spring-planted brown trout were recovered during the open season. Holloway and Chamberlain (1942), checking a river in the Pisgah National Game Reserve, found a return of 10.6 per cent of the fall-planted brown trout and 14.4 per cent of the spring-planted fish in the first season.

Of the fish planted on July 17, 1942, in Duschee Creek, 5.0 per cent of the brook trout and 9.6 per cent of the brown trout were returned

during that season, and no brook trout and 2.0 per cent of the brown trout were captured by anglers in 1943 (Table 3). Thus, in two seasons 5.0 per cent of the brook trout and 11.6 per cent of the brown trout were recovered. The low return of fish in 1942 is attributed for the most part to the light fishing load and the short time the fish were subjected to angling (Table 1). From the brown trout planted in November 1942, 21.7 per cent were returned during 1943, and from the April 1943 stocking, 26.2 per cent of the brook trout and 28.0 per

TABLE 3.—*Summary of data on tagged fish planted in Duschee Creek and recovered in 1942 and 1943*

Date of planting and species of trout	Number of tagged fish	Recovered, 1942			Recovered, 1943		
		Total number of recoveries	Percentage of tagged fish	Percentage of tagged fish in total catch	Total number of recoveries	Percentage of tagged fish	Percent of tagged fish in total catch
Summer, 1942							
Brook	500	25	5.0	3.0	0	0.0	0.0
Brown	500	48	9.6	5.8	10	2.0	0.3
Total	1,000	73	7.3	8.8	10	1.0	0.3
Fall, 1942							
Brown	1,000	....	....	....	217	21.7	6.3
Spring, 1943							
Brook	500	....	....	....	131	26.2	3.8
Brown	500	....	....	....	140	28.0	4.1
Total	1,000	....	....	....	271	27.1	7.9
Totals							
Brook	1,000	25	....	3.0	131	....	3.8
Brown	2,000	48	....	5.8	367	....	10.7
All fish	3,000	73	....	8.8	498	....	14.5

TABLE 4.—*The total number of tagged fish returned after succeeding intervals expressed as percentage of total marked fish recovered from Duschee Creek during the 1942 season from plantings made in the summer of that year*

Interval	Species of trout		
	Brown[1]	Brook[2]	Brown and brook[3]
July 17-23	35.4	64.0	45.2
July 24-30	50.0	96.0	65.8
July 31-August 6	68.8	100.0	79.5
August 7-13	87.5	....	91.8
August 14-20	91.6	....	94.5
August 21-27	97.9	....	98.6
August 28-September 1	100.0	....	100.0

[1]Total of 48 tags recovered.
[2]Total of 25 tags recovered.
[3]Total of 73 tags recovered.

cent of the brown trout were creeled before September 1 of that year. During the current season, 27.1 per cent of the combined spring plantings was captured. The outstanding feature of these data is the high return of fall-planted brown trout, which was only 5.4 per cent less than that of the spring plantings.

Rate of return of marked fish.—In the 1942 season, 79.5 per cent of all marked trout, 100 per cent of the brook trout, and 68.8 per cent of the brown trout which were recovered during that year entered the

catch within 3 weeks after planting (Table 4). During 1943, the return of marked fish from all plantings was rapid. At the end of the first 2 days of fishing, 58.0 per cent of all tagged fish caught in this season had been returned (Table 5). After 4 weeks, 85.3 per cent of all tagged fish recovered had entered the catch. By the end of the third week, 90.0 per cent of the fish recovered from the July, 1942, planting and 88.0 per cent from the November, 1942, planting had been caught. Brown trout planted in the spring of 1943 continued to appear in the catch until August 8, but the brook trout planted at the same time were last taken on July 4. At the end of the first week of the 1943 season, 73.0 per cent of the spring-planted brook trout and 39.3 per cent of the spring-planted brown trout had been caught. From the returns of two seasons, it appears that planted trout contribute substantially to the catch only for the first 3 or 4 weeks of fishing.

Contribution of planted fish to the catch.—The contribution of planted fish to the total catch from Duschee Creek was substantial but nevertheless indicated that a large part of the fishing load was sustained by natural reproduction. In 1942, marked fish comprised 8.8 per cent of the total catch taken after July 17 (brook trout—3.0 per cent; brown trout—5.8 per cent). Marked brook trout, however, provided 36.2 per cent of the total season's catch of this species while marked brown trout comprised only 7.1 per cent of all brown trout caught. During the 1943 angling season, marked and unmarked planted fish contributed 22.7 per cent to the total catch of trout. Eight weeks before the marked trout were planted in the fall of 1942, 1,280 unmarked brown trout were placed in the stream. Assuming that these fish were caught in proportion to and at the same rate as the marked fish, brown trout from all plantings comprised 26.7 per cent of the total return of this species in 1943. Planted fish made up 23.9 per cent of the total brook trout caught. Because a large number of rainbow trout contributed to the total catch, planted brown trout made up only 18.8 per cent and brook trout only 3.8 per cent of the entire creel. In the early part of the season, marked fish contributed as much as 36.7 per cent to a single week's catch (Table 2).

Knife River

Five hundred marked brook trout and a like number of marked brown trout were placed in the Knife River on October 16, 1942, and an identical planting was made on April 30, 1943. The fish of both plantings were held in the hatchery for 5 days after marking before they were taken to the stream. The brown trout were placed in the lower and normally warmer portion of the stream and the brook trout in the headwaters. For the most part, the brown trout were placed in a newly improved area which had previously been poor fishing water. During the 1943 trout season, a creel census was maintained in which

between 85 and 95 per cent of all fishermen were contacted. The stream was thoroughly posted and tag receptacles were placed at convenient points along the banks. Although all fishermen were not interviewed by the census clerks, it is probable that only a small percentage of the tags taken were not returned.

TABLE 5.—*The total number of tagged fish returned after succeeding intervals expressed as percentage of total marked fish recovered from Duschee Creek during the 1943 season*

Interval	Summer planting 1942, Brown trout[1]	Fall planting 1942, Brown trout[2]	Spring planting 1943		Total for all plantings[5]
			Brown[3] trout	Brook[4] trout	
May 1	30.0	63.6	21.4	49.6	47.4
May 2	70.0	71.9	32.9	61.1	58.0
May 3-9	80.0	77.9	39.3	73.3	65.9
May 10-16	80.0	84.8	51.4	75.6	72.9
May 17-23	90.0	88.0	66.4	84.0	80.9
May 24-30	90.0	90.3	78.5	84.0	85.3
May 31-June 6	100.0	94.0	86.4	84.0	89.4
June 7-13	....	95.9	90.0	84.7	91.4
June 14-20	....	97.2	92.1	87.8	93.4
June 21-27	....	98.6	92.9	99.2	97.2
June 28-July 4	....	99.1	95.7	100.0	98.4
July 5-11	....	100.0	95.7	....	98.8
July 12-18	....	....	96.4	....	99.0
July 19-25	....	....	97.1	....	99.2
July 26-August 1	....	....	97.1	....	99.2
August 2-8	....	....	100.0	....	100.0
August 9-15	....	....	....	....	....
August 16-22	....	....	....	....	....
August 23-29	....	....	....	....	....
August 30-September 1	....	....	....	....	....

[1]Total of 10 tags recovered.
[2]Total of 217 tags recovered.
[3]Total of 140 tags recovered.
[4]Total of 131 tags recovered.
[5]Total of 498 tags recovered.

TABLE 6.—*Summary of creel census on Knife River—1943*

Interval	Total number of fishermen	Total number of fish	Catch per hour	Percentage of marked fish in the catch	Number of trout taken		
					Brown	Brook	Rainbow
May 1	83	149	0.69	8.7	15	115	19
May 2	86	91	0.47	7.7	10	77	4
May 3-9	60	151	0.87	26.5	14	133	4
May 10-16	32	76	0.80	22.4	6	66	4
May 17-23	32	86	0.96	33.7	8	68	10
May 24-30	30	89	0.91	21.3	12	62	15
May 31-June 6	16	17	0.51	11.8	1	16	0
June 7-13	31	58	0.97	19.0	11	44	3
June 14-20	15	65	1.71	4.6	3	57	4
June 21-27	23	95	1.68	9.5	6	74	15
June 28-July 4	24	68	0.84	4.1	5	42	21
July 5-11	13	29	0.71	10.3	0	29	0
July 12-18	16	35	1.56	0.0	3	23	9
July 19-25	12	19	0.58	5.3	2	16	1
July 26-August 1	13	34	0.99	0.0	3	16	15
August 2-8	15	69	2.03	0.0	0	51	18
August 9-15	15	43	1.16	4.7	0	32	11
August 16-22	14	38	1.09	0.0	1	24	13
August 23-29	17	21	0.53	4.8	2	18	1
August 30-31	2	6	1.20	0.0	0	6	0
Entire season	549	1,239[1]	0.87	12.9	102	969	167

[1]One fish of this total was unspecified as to kind of trout.

Creel census.—The fishing was light on the Knife River during 1943, especially in the areas where brown trout had been planted. During the entire season, 549 anglers took 1,239 fish of which 969 were brook trout, 167 rainbow trout, 102 brown trout, and one unspecified (Table 6). They fished an average of 2.6 hours and captured trout at the rate of 0.87 fish per hour. Although the rate of take varied widely during the several weekly intervals, no definite trend was apparent. No relationship between the rate of capture and the number of anglers was noted, and the decline in the total number of fish caught as the season progressed was the result of a progressive decrease in fishing intensity. As in Duschee Creek, most of the fishing was done during the first 6 weeks.

Recoveries of marked fish.—As has been found by previous workers, the recovery of fall-planted fish was much lower than that of trout planted just before the opening of the season (Table 7). One and nine-tenths per cent of the total fall planting and 14.1 per cent of the total spring planting were returned during the 1943 fishing season. A higher percentage of brook trout than of brown trout was recovered from both plantings. In 1943, 2.4 per cent of the brook trout and 1.4 per cent of the brown trout planted in the fall and 19.6 per cent of the brook trout and 8.6 per cent of the brown trout planted in the spring were taken during the open season. The low recovery of the brown trout is probably correlated with lower fishing intensity in the area where this species was stocked. Average returns for fall and spring plantings were similar to those reported by Smith (1941) from the Salmon Trout River on the south shore of Lake Superior, but were below the returns reported from most other waters.

Rate of return of marked fish.—In the Knife River most of the tagged fish that were recovered were caught in the first few weeks of the open season, but returns from the fall planting continued until August 15 and from the spring planting until the last week of the season (Table 8). By the end of the fourth week of fishing, 78.1 per cent of all marked fish caught in 1943 had been taken. At the end of this period, 83.3 per cent of the fall-planted brook trout, 93.9 per cent of the spring-planted brook trout, 71.4 per cent of the fall-planted brown trout, and 41.9 per cent of the spring-planted brown trout which were recovered during the season had been caught.

Contribution of planted fish to the catch.—As in Duschee Creek, native fish provided most of the catch in the Knife River. During the 1943 season, marked and unmarked hatchery trout made up 23.0 per cent of the total take. Fourteen days after the opening date in the spring of 1943, 688 unmarked brook trout were planted in the stream. Assuming that these fish were caught in the same proportion as marked fish, planted brook trout made up 24.3 per cent of the catch of that species. Planted brown trout made up 49.0 per cent of all brown trout taken. Since rainbow trout helped make up the complete catch, planted

TABLE 7.—*Summary of tagged fish planted in Knife River in the fall of 1492 and the spring of 1943, and recovered in 1943*

Date of planting and species of trout	Number of tagged fish	Total number of recoveries	Percentage of tagged fish	Percentage of tagged fish in total catch
Fall, 1942				
Brown	500	7	1.4	0.6
Brook	500	12	2.4	1.0
Total	1,000	19	1.9	1.5
Spring, 1943				
Brown	500	43	8.6	3.5
Brook	500	98	19.6	7.9
Total	1,000	141	14.1	11.4
Totals				
Brown	1,000	50	....	4.0
Brook	1,000	110	....	8.9
All fish	2,000	160	....	12.9

TABLE 8.—*The total number of tagged fish returned after succeeding intervals expressed as percentage of total marked fish recovered from the Knife River during the 1943 season*

Interval	Fall planting 1942		Spring planting 1943		Total for all plantings[5]
	Brown trout[1]	Brook trout[2]	Brown trout[3]	Brook trout[4]	
May 1	0.0	16.7	9.3	7.1	8.1
May 2	42.9	16.7	9.3	11.2	12.5
May 3-9	42.9	33.3	18.6	45.9	37.5
May 10-16	42.9	41.7	20.9	61.2	48.1
May 17-23	57.1	41.7	34.9	83.7	66.3
May 24-30	71.4	83.3	41.9	93.9	78.1
May 31-June 6	85.7	83.3	41.9	94.9	79.4
June 7-13	85.7	83.3	60.5	98.0	86.3
June 14-20	100.0	83.3	65.1	98.0	88.1
June 21-27	....	83.3	83.7	99.0	93.8
June 28-July 4	....	83.3	88.4	100.0	95.6
July 5-11	....	91.7	93.0	....	97.5
July 12-18	....	91.7	93.0	....	97.5
July 19-25	....	91.7	95.3	....	98.1
July 26-August 1	....	91.7	95.3	....	98.1
August 2-8	....	91.7	95.3	....	98.1
August 9-15	....	100.0	97.7	....	99.4
August 16-22	....	....	97.7	....	99.4
August 23-29	....	....	100.0	....	100.0
August 30-September 1	....	....	....	....	....

[1]Total of 7 tags recovered.
[2]Total of 12 tags recovered.
[3]Total of 43 tags recovered.
[4]Total of 98 tags recovered.
[5]Total of 160 tags recovered.

brook trout comprised 19.0 per cent and planted brown trout 4.0 per cent of the total number of trout entering the fishermen's creels.

CONCLUSIONS

It is evident from results obtained in Duschee Creek that under certain conditions the survival of fall-planted trout, 7 to 10 inches long, compares favorably with that of spring-planted fish. Although there was a comparatively good return of fall-planted fish, the percentage was less than that of the spring plants and they remained in the catch for a shorter period of time after the opening of the season. As was found by Holloway and Chamberlain (1942) for southern streams,

brown trout planted in the spring or during the open season in Duschee Creek made little contribution to the catch of the succeeding year. Planted brook trout are not as satisfactory as brown trout in this stream because their survival is lower, they do not carry over from season to season, and they are caught more rapidly after planting.

In the Knife River, spring planting of 7- to 10-inch hatchery fish proved to be far superior to fall planting. The small recoveries of brown trout were probably not a reflection of low survival, but rather of low fishing load.

From a consideration of all the data it appears that spring planting is more effective than the best fall planting and that in the streams considered here, planted fish, 7 to 10 inches long, contribute materially to the fishermen's success during the period of greatest angling intensity. Planting after the middle of June is not justified because the decreased fishing load after that time will not insure effective utilization.

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SEASONAL CHANGES IN GROWTH, MORTALITY, AND CONDITION OF RAINBOW TROUT FOLLOWING PLANTING

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ABSTRACT

The results of experimental plantings of rainbow trout in Convict Creek (California) are presented as related principally to changes in growth, mortality, and condition from month to month over two summer seasons. Survivals are discussed in relation to a food-requirement ratio that has been shown to correlate positively with survival rates obtained.

Survivals of 33 per cent and 56 per cent were obtained over periods of 151 days and 179 days, respectively. Wild fish grew approximately twice as fast as planted fish each season. The coefficient of condition of the planted rainbow trout fell consistently for the first few months following planting. A parallel loss in condition of wild trout occurred but was less marked. "Conditioning" of hatchery trout for from 1 to 3 weeks prior to planting had no appreciable effect on survival rates.

INTRODUCTION

The data presented here were obtained from plantings of rainbow trout in 1941 and 1942 at the Convict Creek Experiment Station in eastern California. Experimental stocking of rainbow trout under natural conditions has been conducted there from 1938 to 1942, inclusive. Survival data from 63 test plantings were presented by Needham and Slater (1944). Needham and Rayner (1939) described the techniques and stream sections used.

METHODS

The experiments reported here were carried out to determine the changes in growth, mortality, and condition through two summer seasons. In 1941, the experiment was operated 179 days, and in 1942, 151 days. Stream-section A was used. This section is 310 feet long and has an average width of approximately 7.5 feet.

A total of 168 fingerling rainbow trout (*Salmo gairdnerii*) with an average total length of 3.7 inches were planted each season. Before stocking, the section was pumped dry and all wild trout were removed. These wild fish were weighed and measured, and returned to the section. In 1941, each fish was weighed and measured separately both at the beginning of the experiment and at subsequent removals except in the instances cited below. This treatment caused a somewhat high mortality that year. In 1942, each fish was measured separately as before, but average weights were determined by weighing all individuals in each size group together in water.

Mortality

As a result of improving the method of handling the fish, survival increased from 33 per cent in 1941 to 56 per cent in 1942 (Fig. 1). The difference between survivals is greater when considered on the basis of food competition. Needham and Slater (1944) have shown that survival of planted trout correlates positively with the ratio of the weight of planted fish to that of all fish, both wild and planted. This relationship is expressed as a percentage ratio. In other words, food requirements are proportional to weight, and a measure of food competition and predation between wild and planted trout in any defined area is given as a percentage ratio which is computed as follows:

$$\text{Food requirement ratio} = 100 \times \frac{\text{Weight of planted fish}}{\text{Weight of all fish (planted and wild)}}$$

The ratio was 65.5 per cent in July 1941 and only 36.5 per cent in the same month in 1942 (Table 1). Consequently, survival should have

TABLE 1.—*Comparison of food-requirement ratios in Section A, 1941 and 1942*

1941		1942		Difference between 1941 and 1942
Date	Food ratio	Date	Food ratio	
May 3	77.2	May 5	43.7	33.5
June 1	67.4	June 5	40.0	27.4
July 1	65.5	July 5	36.5	29.0
July 31	49.1	August 4	33.8	15.3
August 29	48.5	September 3	45.0	3.5
September 30	46.5	October 3	43.6	2.9
October 29	47.3	....	....	....

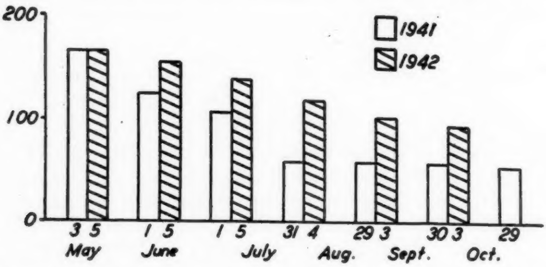

FIGURE 1.—Number of rainbow trout surviving in Convict Creek

been higher, not lower, in 1941. Inasmuch as the 1942 survival was near the average for 28 planting experiments (Needham and Slater, 1944), it must be assumed that survival in 1941 was below expectations. Trends in the changes in growth and condition do not appear to have been markedly altered despite the abnormal mortality (Figures 2 and 3).

Fish of the 1941 planting grew much faster on the average than did

those of the 1942 planting, and the differences in growth rate (Fig. 2) correlate fairly well with the differences in the food-requirement ratios (Table 1).

It is notable from Figure 2 that the rate of growth in August and September of 1941 was less than in the same months of 1942 even though the differences in food-requirement ratios still favored the 1941 planting (Table 1). Probably the method of weighing use in 1941 retarded the growth somewhat in these months. Nevertheless, the close correlation between the food-requirement ratio and the rate of growth in these experiments is further proof of the poor economy involved in planting trout in waters supporting heavy stocks of wild trout.

Growth

Fish of the 1941 planting had nearly twice the average growth increment of those of the 1942 planting due primarily to the relative paucity of wild trout in the former year (Table 2). The increments in both these years are of the same order as those obtained from other experimental plantings in this section in 1938, 1939, and 1940. In this

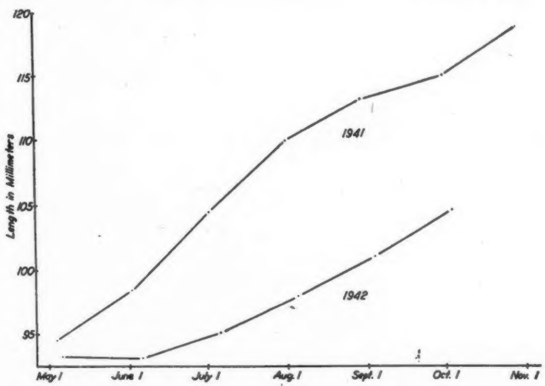

FIGURE 2.—Growth of rainbow trout in Convict Creek

connection, it is interesting to note that all wild fish in this section had growth increments roughly twice as great as those of planted trout. For example, in 1941 the planted rainbow trout grew an average of 0.96 inches in total length, while 27 brown trout grew from an average total length of 4.47 inches to a length of 6.14 inches, an increment of 1.67 inches. In 1942, the situation was exactly comparable. The planted rainbow trout grew an average of 0.44 inches while the average total length of 38 wild brown trout increased from 4.67 inches to 5.57 inches, or 0.90 inch. The fact that three wild rainbow trout of the year grew

0.84 in in 1942 further confirms the above relations. These differences in the growth increments between planted trout and wild trout are probably the result of the acclimatization process the course of which may be outlined by the changes in condition of the fish (Figure 2).

Water temperatures of Convict Creek expressed as mean daily maximum were 58.6 in 1941 and 59.5 in 1942, over corresponding periods. Thus temperature conditions were slightly more favorable for growth in 1942.

Changes in Condition

The course of changes in the coefficient of condition[1] of trout following planting is easily calculated from the data of these experiments (Figure 3 and Table 3). It will be noted that the progress of events in the two years was very similar. The marked decline in condition of the planted fish occurred one month earlier, however, in 1942, and the drop was nearly twice as great as in 1941. This difference was probably due to the more severe competition obtaining in 1942. In 1941, the initial slight decrease followed by an increase the next month was probably not the true trend. These two observations were based on weight measurements of a sample of 50 fish, less than half the number present; they were consequently subject to more error than the other observations. An initial increase in the average coefficient of condition of planted trout might occur soon after planting, possibly due to early and greater mortality among the weaker fish in poor condition.

The marked decline in condition that followed for planted rainbow trout may have been a result of acclimatization or hardening in their environment. This explanation does not suffice without qualification, however, for the wild brown trout also experienced a marked decline in condition immediately after the hatchery fish were planted (Figure 3). This decline for the wild trout might be explained partly by the experimental handling and partly by the additional competition brought about by the planting of the rainbow trout. It is believed, however, that if these factors were not operative, loss in condition still might have occurred as a result of rapid growth over the summer season. The increase in condition in the fall probably resulted from the more intensive feeding that has been observed to take place in the late fall in high mountain streams in the region of Convict Creek.

The decline in condition of planted rainbow trout was greater than that for wild brown trout. Considering size and species differences, the brown trout would normally have shown lower, rather than higher, coefficients of condition (Embody, 1937). The coefficients of condition of the planted rainbow trout were higher than those of the brown trout for only approximately one month in 1942 (Figure 3).

[1]The coefficient of condition, commonly known as the condition factor, is a measure of the relative plumpness of a fish in relation to its length. It was used by Hecht (1916), who gave the following formula for the computation of the coefficient a:

$$a = \frac{100 \times \text{weight in grams}}{(\text{length in centimeters})^3}$$

TABLE 2.—*Changes in total length in inches of wild brown trout and planted rainbow trout during the 1941 and 1942 seasons*

1941			1942		
Date	Wild brown trout	Planted rainbow trout	Date	Wild brown trout	Planted rainbow trout
May 3	4.47	3.71	May 5	4.67	3.67
June 1	4.97	3.88	June 5	4.91	3.67
July 1	5.19	4.11	July 5	5.24	3.74
July 31	5.50	4.33	August 4	5.41	3.86
August 29	5.80	4.46	September 3	5.54	4.00
September 30	6.02	4.53	October 3	5.57	4.11
October 29	6.14	4.67	....	......	......

TABLE 3.—*Changes in coefficient of condition of wild brown trout and planted rainbow trout during the 1941 and 1942 seasons*

1941			1942		
Date	Wild brown trout	Planted rainbow trout	Date	Wild brown trout	Planted rainbow trout
May 3	1.291	1.180	May 5	1.209	1.164
June 1	1.223	1.154	June 5	1.127	1.190
July 1	1.141	1.189	July 5	1.115	1.081
July 31	1.160	1.150	August 4	1.119	1.031
August 29	1.122	1.097	September 3	....	1.036
September 30	1.100	1.113	October 3	1.082	1.055
October 29	1.128	1.161	....	....	....

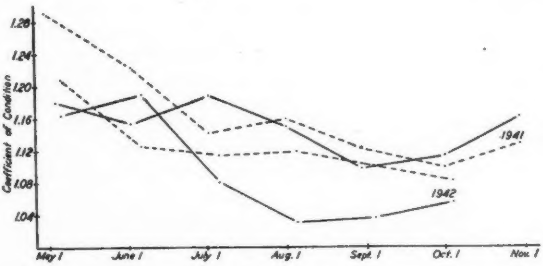

FIGURE 3.—Changes in coefficient of condition of trout in Convict Creek. Rainbow trout—solid line; brown trout- - -broken line.

It must be concluded from these observations that trout planted in streams lose condition during the first 3 or 4 months after planting. This loss doubtless includes that which might normally occur during the summer growth season, but it probably resulted primarily from acclimatization and only secondarily from the competition with wild trout.

EXPERIMENTAL "CONDITIONING" PRIOR TO PLANTING

The term "conditioning" as used here implies treating the hatchery fish in such a way as to prepare them physiologically for the natural environment into which they are to be planted. To be effective, the

process probably should be one of gradual change from the hatchery environment to the natural environment over a period of time varying with the degree of change involved in the transfer. Such a process is impractical in most cases because it would entail too great an expenditure of time and funds. Experimental conditioning was studied at Convict Creek in 1941 and 1942. In 1941, conditioning consisted of holding the fish in a section of natural stream for one week prior to planting. In 1942, the period was lengthened to three weeks, and the trout were held in dirt-bottom pools built at the side of the main creek. After conditioning, equal numbers of conditioned and unconditioned fish were planted in the same section of stream to test survival and growth under identical ecological conditions. Each of these experiments was duplicated in a separate stream section each year so that a total of 12 plantings was made over the two seasons covered.

One paired experiment was carried out each year with brown trout fingerlings (around 1.4 inches, total length). Two paired experiments were made each year with rainbow trout—one with small (around 1.5 inches, total length) and one with large (around 3.5 inches) fingerlings. A total of 484 small fingerling brown trout and rainbow trout were used in each planting in 1941. In 1942, 362 small rainbow trout and 436 small brown trout were in each planting. In each year, 70 large rainbow trout were planted.

In 1941, no record was obtained of mortality during the conditioning period. In 1942, no losses of the larger fingerling rainbow trout occurred during conditioning, but the small brown trout fingerlings suffered a loss of 24.7 per cent over the 3-week period. The mortality of the small rainbow trout could not be accurately determined because the screen at the head pool in which these fish were held became plugged and water ran around it, permitting the fish to escape upstream.

The experiments were inconclusive on the basis of the survivals obtained. The 1941 experiments with rainbow trout demonstrated either no difference between the survival of the conditioned and the unconditioned trout or a slight advantage in favor of the unconditioned ones. The 1942 experiments with rainbow trout gave a very slight advantage to the "conditioned" fish in three plantings and a slight advantage to the unconditioned ones in one planting of large fingerlings.

The results of experiments with brown trout were more consistent. In the two 1941 plantings the survival of unconditioned fish was the greater by 7 and 10 per cent. The two 1942 plantings showed advantage to the conditioned fish of 8 and 8.5 per cent.

As was stated earlier, 24.7 per cent of the brown trout were lost during conditioning in 1942. During the course of one experiment, another mortality of 61.9 per cent occurred among the unconditioned fish planted and 53.2 per cent among the conditioned fish. In the other section, mortalities were 40.4 per cent and 32.1 per cent, respectively.

Losses during conditioning plus those following planting were greater than if the fish had been planted directly without conditioning.

It can be concluded that conditioning as attempted here was an uneconomic process and was not justified by the results obtained. Further studies of conditioning must be made before its real value can be determined. In any case conditioning should be supplemented by carefully administered planting. In the planting the fish should be so distributed as to break down the gregarious habits established at the hatchery. In addition, the usual recommendations as to the selection of favorable conditions of food, shelter, temperature, and other factors should be followed.

Further evidence bearing on the efficacy of conditioning is given by unpublished data of Dr. H. S. Davis from an experiment conducted in North Creek near Leetown, West Virginia. Rainbow trout of around 9 inches, total length, were used and conditioning encompassed several months. "The fish . . . were conditioned . . . in sections of the natural creek beds, which were screened to prevent escape of the fish. These fish were fed a small amount of artificial food, but depended largely on natural food which they foraged for themselves." A total of 504 hatchery fish and 509 conditioned fish were planted at the same time and under the same conditions in North Creek.

The results of this experiment show definite advantage both for and against conditioning depending on the result desired. Fewer of the conditioned fish were taken by anglers in the season immediately following the spring planting (27 per cent as compared with 42 per cent of the unconditioned fish) and they more nearly resembled wild fish in appearance and habits than did the fish planted directly from the hatchery. These results indicate an advantage for conditioning where the object of planting is to build up a self-sustaining resident stock. But if the object of planting is to provide large, legal-sized trout for immediate catching in order to alleviate the effects of over-fishing, conditioning would defeat the purpose.

Summary

1. Changes in growth, mortality, and condition of 168 rainbow trout following planting were determined at regular intervals during the growing seasons of 1941 and 1942.

2. The survival was 33 per cent in 1941, and 56 per cent in 1942. Handling caused a heavier than normal mortality in 1941.

3. Growth of fish planted in 1941 was nearly twice as fast as growth of those planted in 1942 because of less competition from wild fish. Wild brown trout grew, roughly, twice as fast as the planted rainbow trout.

4. The coefficient of condition of hatchery trout fell during the first 3 to 4 months following planting during the initial period of harden-

ing in a new environment. A parallel but less pronounced loss in condition of wild trout was noted.

5. Considering the methods and size of fish used, hardening or conditioning of trout for periods of 1 week and 3 weeks, respectively, was uneconomical and not justified in terms of resulting survivals.

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GROWTH, LENGTH-WEIGHT RELATIONSHIP AND POPULATION FLUCTUATIONS OF THE TULLIBEE, *LEUCICHTHYS ARTEDI TULLIBEE* (RICHARDSON), WITH REFERENCE TO THE COMMERCIAL FISHERIES, LAKE OF THE WOODS, MINNESOTA

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ABSTRACT

The tullibee, *Leucichthys artedi tullibee* (Richardson), is one of the most important commercial fishes in the Lake of the Woods. The relationship between standard length and the anterior scale radii of the tullibee can be described by a third degree parabola. Growth calculations were made using the corrected body-scale relationship. The greatest growth in length occurs during the first year of life, and the annual increment decreases each succeeding year. Males and females grow at approximately the same rate. The appearance of Lee's phenomenon is pronounced and probably is due to the differential mortality between slow-growing and fast-growing fish. No correlation could be demonstrated between annual fluctuations in growth rate and fluctuations in temperature or rainfall.

The weight increases approximately at a rate proportional to the 3.2 power of the standard length. The average "*K*" of 1.99 indicates that the tullibee are relatively heavy-bodied. The average sex ratio was two males to every three females, and the females were longer-lived than the males. The majority of the tullibee spawn for the first time at the end of the third year of life.

Tullibee are often parasitized by *Triaenophorus robustus* and in the past have been banned from the market on this account. The commercial take of tullibee was small from 1933 through 1937 when there was no market for the fish. A reduction in the incidence of parasitism opened the market and over 2,000,000 pounds were taken in 1939 and 1940. This change in commercial take was followed by a marked change in the age and size distribution of the tullibee. When intensive fishing was first begun in 1939, most of the tullibee were more than 4 years old. By 1941 only 20 per cent of the commercial take were of that age. The dependence of the fisheries on 2- and 3-year-old tullibee in 1941, 1942, and 1943 indicates that a population sufficient to support a fishery of maximum yield is not being maintained.

INTRODUCTION

The tullibee, *Leucichthys artedi tullibee* (Richardson), is a deep-bodied cisco found in Minnesota and neighboring areas.[1] It is an im-

[1]The name "tullibee" is used to designate any deep-bodied form of cisco or lake herring in Minnesota or neighboring areas (Eddy and Surber, 1943). Detailed systematic studies of the tullibee from the Lake of the Woods have not been completed, but it is believed that the Lake of the Woods form is *Leucichthys artedi tullibee* (Richardson). Koelz (1931) reported this subspecies from the Lake of the Woods. Studies by Hile (1936) indicate that many of the subspecies of *Leucichthys artedi* are invalid and are merely growth forms.

portant commercial fish in the Lake of the Woods, in Rainy Lake, and in several Manitoban lakes. In 1940, the commercial production of tullibee in Minnesota waters was over a million pounds and approximately one-half of the gross income to the Lake of the Woods fishermen came from this species. Extensive life history studies of various subspecies of the cisco, *Leucichthys artedi* (Le Sueur), have been published (Van Oosten, 1929; Hile, 1936b; Stone, 1938) but information on the tullibee is scanty (Bajkov, 1930; Eddy and Carlander, 1942). Data on the rate of growth, length-weight relationship, sex ratios, age at maturity, and population fluctuations of the tullibee were collected during a fishery investigation of Lake of the Woods initiated in 1939 by the Minnesota Department of Conservation and the University of Minnesota, which is being continued by the Bureau of Fisheries Research of the Department of Conservation.

Body-Scale Relationship and Computation of Growth Rates

The scale method of growth analysis was demonstrated to be valid for *Leucichthys artedi* by Van Oosten (1929). Analysis of the growth data by methods similar to those he used indicate that the method is applicable to Lake of the Woods tullibee. Before the calculation of the growth rates from the scale measurements was attempted, the relationship between the growth of the scale and of the standard length was determined.[2] Scales for the study of this relationship were taken near the lateral line immediately above the posterior edge of the pectoral fin. Instead of using "key" scales as Hile (1941) and others have done, several scales from each fish were measured and the measurements were averaged. It was evident that the relationship between the scale radius and standard length was not a straight line (Table 1), but could be best described by a third degree parabola with the following formula:

$$L = 3.418 \text{ millimeters} + 7.49\,R - 0.1559\,R^2 + 0.00207\,R^3 - 0.000009\,R^4,$$

if $L =$ standard length in millimeters,
and $R =$ anterior radius of the scale in millimeters times 16.4.

Van Oosten (1929) demonstrated that after the first annulus the ratio of the scale diameter to the body length is so nearly constant in *Leucichthys artedi* that growth calculations can be made on a direct proportion basis without correction. However, if anterior radii are

[2]Standard lengths were recorded for each fish and all measurements are given as standard lengths in this report. Conversion from one form of measurement to another may be made as follows:

Fork length = 1.076 standard lengths
Total length = 1.175 standard lengths
Total length = 1.095 fork lengths

All fish were measured while fresh.

TABLE 1.—*Average anterior radius (X 16.4) of scales from Lake of the Woods tullibee at various body lengths*

Number of fish	Standard lengths in millimeters	Average radius in millimeters (× 16.4)	Calculated radius[1]
80	57.7	9.5	10.0
55	65.6	10.8	11.6
72	78.0	15.1	14.4
22	126.8	31.1	29.0
24	137.8	32.8	33.0
17	145.5	36.8	36.0
12	153.9	36.9	39.1
28	166.0	45.6	43.7
66	176.1	48.0	47.3
46	185.1	50.4	50.4
36	195.2	53.4	53.8
88	206.7	57.3	57.4
93	216.3	61.7	60.3
102	225.8	63.2	63.1
44	234.2	64.3	65.4
102	246.0	67.4	68.7
277	255.8	71.1	71.3
194	267.2	73.0	74.3
422	277.0	77.1	76.9
195	286.6	80.0	79.3
326	295.0	83.0	81.5
314	304.1	84.4	84.0
215	315.7	88.3	87.6
110	326.6	92.9	92.1
16	335.4	97.6	95.2
21	343.9	94.7	97.7
12	357.0	104.9	101.2

[1]Calculated radii were used in making all growth computations. They were calculated with the body-scale relationship formula given in the text.

used, corrections must be made. Most workers have, therefore, used scale diameters for growth studies of lake herring. In the present study, scale radius measurements were used throughout. Annuli are sometimes difficult to locate on the posterior field, particularly in the older fishes. The principal objection to the use of radius measurements with coregonid scales is that the foci are often so large that it is difficult to determine the exact center. The focci of scales from Lake of the Woods tullibee were not extremely large, and it is believed that errors due to difficulties in locating the exact center of the scales were small. All growth calculations were made in the manner described by Hile (1941) using the body-scale formula given in the preceding paragraph.

AGE AND RATE OF GROWTH

Growth rates were calculated for 1,561 tullibee collected from 1939 to 1943 in pound nets and in gill nets with various mesh sizes (Table 2). The greatest growth in length occurs in the first year of life, and the annual increment decreases each successive year. Hile (1936b) described the cisco-type of growth as follows: "The greatest growth in length occurs in the first year of life. The growth of the second year is large, but less than that of the first. Growth decreases markedly in the third year of life. Throughout the later years the annual incre-

ment of growth in length tends to remain fairly constant." The growth of the Lake of the Woods tullibee differs from this type in two respects: (1) the decline in growth during the third year is not more marked than in other years, and (2) the annual increments in later years are not constant but tend to decrease as the fish grow older. Clear Lake ciscoes (Hile, 1936b), which are deep-bodied forms like Lake of the Woods tullibee, showed a similar divergence from the "cisco-type" of growth.[3]

Since no significant differences were noted in the growth rates of tullibee collected at Lake of the Woods in the various years, the data from

TABLE 2.—*Average calculated standard lengths and annual increments in length and weight of tullibee collected at Lake of the Woods, 1939 to 1943*

Age Group	Number examined	Average standard length in millimeters at annulus									
		1	2	3	4	5	6	7	8	9	10
I	106	113	....	....	....	....	....	....	....	....	....
II	225	112	177	....	....	....	....	....	....	....	....
III	394	105	165	220	....	....	....	....	....	....	....
IV	447	104	156	205	252	....	....	....	....	....	....
V	289	107	155	199	241	280	....	....	....	....	....
VI	79	103	149	187	232	262	295	....	....	....	....
VII	14	104	150	189	227	262	294	319	....	....	....
VIII	5	90	139	179	221	256	288	313	328	....	....
X	2	110	157	195	235	276	304	332	356	380	402
Grand average (1,561 fish)		106	161	207	246	275	295	319	336	380	402
Average annual increment in millimeters		106	55	49	45	37	33	25	18	24	22
Annual increment in grams		20	55	101	152	179	208	192	134	224	234

all samples were combined. Data for males and females were also combined after preliminary examination revealed no constant difference. Van Oosten (1929), Cooper (1937), Stone (1938), and Eddy and Carlander (1942) found no significant difference in the growth rates of male and female *Leucichthys artedi*. In one lake studied by Hile (1936b), females grew more rapidly than the males, but in the three other lakes the males and females grew at the same rate.

Lee's phenomenon of apparent change in growth rate was evident in the calculated growth data of Lake of the Woods tullibee collected by various methods and in various calendar years. Size selection by gill nets may have been responsible for Lee's phenomenon in some samples since, within each age group, the nets with large mesh select larger fish than do the nets with small mesh (Table 3). The commercial nets with 4-inch mesh, stretched measure, therefore select only the faster-growing fishes in the young age groups. That Lee's phenomenon is not entirely due to selective sampling, however, is indicated by the

[3]According to Koelz (1931), the Clear Lake ciscoes belong to the subspecies *clarensis*. Clear Lake is the type locality for the subspecies.

presence of the phenomenon in the calculated growth data from samples where size selection would be at a minimum. Even samples collected with standard experimental gill nets with equal lengths of 1½-, 2-, 2½-, 3-, and 4-inch mesh showed the phenomenon. Hile's (1936b) suggestion that the fast-growing fish are shorter-lived than

TABLE 3.—*Average standard lengths of Lake of the Woods tullibee in each age group as determined from samples taken in various sizes of gill-net mesh*

[Number of specimens shown in parentheses]

Year collected	Mesh size in inches (stretched measure)	Average standard length in each age group			
		II	III	IV	V
1939	3	235 (12)	261 (3)	....	....
	3.75	....	272 (5)	279 (2)	311 (1)
	4	....	273 (3)	294 (10)	312 (13)
1940	2.88	226 (12)	260 (3)	....	....
	3.37	242 (2)	270 (9)	284 (3)	286 (2)
	4	....	276 (11)	285 (13)	310 (8)

the slow-growing individuals appears to be the most plausible explanation of Lee's phenomenon in this case.

As was demonstrated for the ciscoes by Van Oosten (1929) and Hile (1936b), growth compensation occurs in the Lake of the Woods tullibee but the compensation is not great enough to overcome any advantage in length which large individuals may hold at the end of thé first year.

In successive calendar years the average annual increments of fish in the same year of life differed significantly (Table 4). The use of

TABLE 4.—*Annual growth increments (in millimeters) of Lake of the Woods tullibee in the 1931 to 1942 year classes during the years 1931 to 1942*

Year of life	Calendar year											
	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
10	....	....	....	....	....	....	....	....	....	22	....	....
9	....	....	....	....	....	....	....	....	24	....	....	....
8	....	....	....	....	....	....	....	28	....	16	....	....
7	....	....	....	....	....	....	26	23	26	24	....	....
6	....	....	....	....	....	29	35	35	27	26	....	....
5	....	....	....	....	41	38	30	34	32	36	43	35
4	....	....	....	44	40	44	47	46	46	43	55	39
3	....	....	36	50	37	45	50	55	54	49	50	56
2	....	45	44	46	48	50	57	62	61	56	57	65
1	106	110	102	108	105	102	107	113	107	107	110	109
Number of fish collected each year												
1939	1	8	60	233	362	213	43	68	....	....	....	....
1940	....	....	....	5	15	20	32	73	3	....	....	....
1941	3	....	4	6	14	37	42	78	43	13	....	....
1942	....	....	....	....	....	....	2	16	32	6	12	....
1943	....	....	....	....	....	....	....	2	7	33	60	10

Hile's (1941) method to evaluate the changes in annual growth rates indicated that the average annual increments increased from 1931 to 1938, decreased during the next 2 years, and increased again in 1941 (Table 5). No correlation could be demonstrated between the flunctuations in rate of growth and the fluctuations in temperature or rainfall.

Although the annual increment in length decreases as the fish grow older, the annual increment in weight increases through the sixth year (Table 2). In the sixth year the average increase in weight was 208 grams, which is more than the increase during the first 3 years of life.

TABLE 5.—*Deviation of the average annual increments of Lake of the Woods tullibee in different calendar years from the 1931-1942 average*

Year	Percentage deviation
1931	—9.5
1932	—5.8
1933	—11.8
1934	—1.4
1935	—8.9
1936	—6.0
1937	—0.3
1938	+11.8
1939	+7.6
1940	+4.1
1941	+12.0
1942	+ 8.5

LENGTH-WEIGHT RELATIONSHIP

The mathematical relationship between the standard length and weight of the Lake-of-the-Woods tullibee (Table 6) can be described by the following formula, computed by the method of least squares:

$$W = 6.06 \times 10^{-5} \times L^{3.2134},$$

where W = weight in grams,
and L = standard length in millimeters

As an indicator of the relative plumpness of a fish, a number of authors have used the coefficient of condition K, where

$$K = \frac{W \times 10^5}{L^3},$$

where W = weight in grams,
and L = standard length in millimeters.

The average K for the Lake of the Woods tullibee collected in October, 1941, and September, 1943, was 1.99. Tullibee less than 200 millimeters in standard length tended to have lower coefficient of condition than the larger fish. There was no significant difference in the coefficients of male and female tullibees. Lake-of-the-Woods tullibee are noticeably heavier-bodied than many other varieties of *Leucichthys artedi,* and the coefficient of condition is, therefore, much higher than that reported by Van Oosten (1929) and Hile (1936b). The highest

average *K* reported by either of them was a value of 1.76 for the Clear Lake, Wisconsin, ciscoes (Hile, 1936b).

TABLE 6.—*Relationship between standard lengths and weights of Lake of the Woods tullibee, 1942-1943*

Average standard length in millimeters	Number	Weight in grams Average	Range	Calculated weight[1]	K Average	Range
158	1	72	....	70	1.82	....
168	2	71	63-75	86	1.47	1.30-1.63
174	7	93	82-98	96	1.76	1.67-1.86
184	11	115	103-136	115	1.87	1.64-2.26
194	10	134	115-167	136	1.83	1.61-2.15
205	22	179	150-208	163	2.07	1.71-2.34
214	31	202	181-234	187	2.04	1.78-2.29
224	26	227	189-254	216	2.00	1.72-2.32
235	37	261	204-290	252	2.01	1.59-2.34
245	38	295	240-352	289	1.99	1.67-2.33
254	32	334	268-400	324	2.03	1.65-2.41
265	36	369	302-484	371	1.99	1.58-2.60
274	24	408	308-500	413	1.98	1.46-2.37
283	12	467	378-536	458	2.06	1.66-2.39
300	1	570	....	553	2.11	....
316	2	551	472-630	653	1.75	1.49-2.01
320	1	656	....	680	2.00	....
Total	293	....	....	....	1.99	1.30-2.60

[1]Log W = —5.2173 + 3.2134 Log L, where W = weight in grams, and L = standard length in millimeters.

SEX RATIO AND AGE AT MATURITY

Natural reproduction is to some extent dependent upon sex ratios and the age at which fish reach maturity. Among the tullibee taken in the experimental gill nets and in the commercial fisheries at Lake of the Woods from 1939 to 1943, the percentage of males varied from 39 to 50 per cent (Table 7). Reasons for the differences in the sex ratios from year to year are not evident at present. The ratio of males to females decreased as the age of the fish increased from 2 to 7 years,

TABLE 7.—*Sex ratios of Lake of the Woods tullibee collected in commercial fisheries and in experimental gill nets, 1939 to 1943*

Age group	1939 Number examined	Percentage male	1941 Number examined	Percentage male	1942 Number examined	Percentage male	1943 Number examined	Percentage male
I	65	52	13	54	2	50	....	....
II	6	83	41	49	4	75	50	46
III	....	....	62	58	32	41	26	23
IV	11	18	31	48	16	44	5	40
V	9	22	25	40	2	50	2	50
VI	4	25	8	37	....	....	....	....
VII	....	....	4	0	....	....	....	....
VIII	....	....	2	100	....	....	....	....
X	....	....	1	100	....	....	....	....
Total	2,978	39	187	50	55	45	83	39

suggesting that the average female is longer-lived than the average mal. However, the three oldest fish examined were males.

Since sex organs were well developed during the summer months, the maturity of individuals could be readily determined. Some fish spawn in their second year of life, but the majority do not spawn

until the end of the third year. This range is similar to that reported for other populations of *Leucichthys artedi* (Cahn, 1927; Van Oosten, 1929; Pritchard, 1931; Hile, 1936b; Stone, 1938).

History of the Commercial Fishery

Commercial fishing has been carried on in Lake of the Woods since 1884, but separate statistics on the tullibee are available only since 1925 (Table 8). According to the older fishermen, tullibee were much less abundant in the early days than in recent years. During the first 30 years of commercial fishing, whitefish, *Coregonus clupeaformis* (Mitchill), were much more abundant than tullibee. From 1910 to 1925, however, the whitefish almost disappeared and tullibee increased in abundance. The commercial production of tullibee in 1925 was over 760,000 pounds. The reason for the low yield of tullibee in 1928 is not known at present. There was no market for tullibee except

TABLE 8.—*Annual commercial yield of tullibee in Lake of the Woods from 1925 to 1942*[1]

Year	Catch in thousand pounds	
	Minnesota	Total
1925	301	767
1926	990	1,154
1927	658	764
1928	220	266
1929	574	612
1930	903	1,005
1931	435	456
1932	1,296	....
1933	293	321
1934	156	237
1935	132	214
1936	103	168
1937	223	320
1938	878	991
1939	911	....
1940	1,185	....
1941	472	....
1942	594	....

[1]Statistics taken from published reports of the Minnesota Department of Conservation and from the annual reports of the former U. S. Bureau of Fisheries, and of the U. S. Fish and Wildlife Service, entitled "Fishery Industries of the United States."

as animal food from 1933 to 1938 and therefore the commercial catch reported for these years was very low. Tullibee are often parasitized by the larval stages of *Triaenophorus robustus*, a tapeworm which matures in the alimentary tract of fishes in the pike and perch families. In 1931-1932, Lake of the Woods tullibee were banned from sale for human consumption because of the high incidence of this parasite. At that time, from 70 to 100 per cent of the tullibee examined were infested and frequently as many as 25 worms were found in a single fish (Hoffman, 1941). Studies in 1939 indicated an improvement which allowed a considerable percentage of the tullibee of 16 ounces or less in weight to pass inspection. An inspection station was set up in Warroad in 1939, and fish that passed inspection were tagged and

marketed. The incidence of parasitism continued to decrease so that even larger tullibee passed inspection in 1940 and 1941. Inspection centers were then established at other points on the lake.

In 1939, the first year that the inspection station was opened at Warroad, the commercial take of tullibee in the Minnesota portion of the lake was over 900,000 pounds, or more than was taken from 1933 through 1937 when the fish could be sold only for mink food. In 1940, the take was over a million pounds, but in 1941 and 1942 the catch was only half as great.

Two general types of nets, gill nets and impounding nets, are used by commercial fishermen in Lake of the Woods. The number of nets of each type has been fairly constant in recent years. In 1939 and 1940, over 90 per cent of the tullibee were taken in gill nets, but in 1941 and 1942 only 64 per cent of the tullibee were taken in the gill nets. A change in fishing practices was largely responsible for this difference in catch. During most of the 1941 and 1942 seasons, the gill nets were floated near the surface instead of being set on the bottom as had been done in previous years. This practice greatly increased the number of yellow pike-perch, *Stizostedion vitreum vitreum* (Mitchill), which were caught (Carlander, 1944), but decreased the number of tullibee taken in the gill nets (Table 9). At the same time, the catch in the impounding nets increased. This increase was probably the result of fishing the nets until mid-July to catch a midsummer run of tullibee instead of pulling the nets out early in July as in previous years.

Changes in the Size and Age Composition of the Population

The change in the fishing intensity for tullibee was followed by marked change in the size and age composition of the population. In 1939, when intensive fishing was resumed after a 5-year period of light fishing for tullibee, the average standard length of fish taken in impounding nets was 294 millimeters and 47 per cent were over 300 millimeters in standard length (Table 10). The size distribution was about the same in 1940, but the number of large fish was greatly reduced in 1941, 1942, and 1943. Less than 2 per cent of the tullibee taken in these years were over 300 millimeters in length, and the average lengths of the tullibee were from 44 to 67 millimeters less than in 1939 and 1940. Commercial fishing, particularly with gill nets (all 4-inch mesh, stretched measure) selects the larger tullibee, and therefore the large fish were the first to show the effects of the intensive fishing of 1939 and 1940. A similar change occurred in the age class composition of the tullibee (Table 11). In 1939, 84 per cent of the tullibee taken in the pound nets were over 4 years of age; in 1940, 59 per cent were over this age; and in 1941, 1942, and 1943, less than 20 per cent were 4 or more years old. In Lake Huron (Van Oosten, 1929) and in Lake Superior (Eddy and Carlander, 1942)

TABLE 9.—*Average annual catch of tullibee in pounds per unit net, Minnesota portion of Lake of the Woods, 1932 to 1942*

Year	Per pound net	Per 1,000 linear feet of gill net
1932	3,093	13,451
1933	687	1,472
1934	51	511
1935	660	275
1936	108	608
1937	8	1,874
1938	655	7,458
1939	409	10,868
1940	1,420	12,020
1941	2,325	3,841
1942	2,369	4,518

TABLE 10.—*Size distribution of tullibee in impounding nets at Lake of the Woods, 1939 to 1943*[1]

Standard length in millimeters	Percentage of total catch in each size class				
	July-September 1939	June-September 1940	June-September 1941	October 1942	September 1943
160-179	....	....	....	2.0	.7
180-199	....	....	6.3	4.7	.7
200-219	1.1	3.1	47.2	5.9	21.2
220-239	4.4	5.0	15.8	35.3	25.5
240-259	7.7	18.2	18.9	44.5	29.9
260-279	12.1	19.1	7.2	7.3	18.6
280-299	27.5	17.2	3.1	1.1	2.7
300-319	32.6	24.7	1.1	....	0.2
320-339	11.4	7.9	0.3	....	0.5
340-359	2.9	2.9	....	0.1	....
360-379	0.4	0.8	0.2	....	....
380-459	....	0.5	....	....	....
Total number	273	378	1,340	747	558
Average standard length	294	285	227	238	241
Standard deviation	27	35	30	21	20

[1]The impounding nets give the best samples for comparing size distributions because these nets may take any fish over a given minimum length, and no selection of certain size classes is to be expected. The sizes of tullibee in the commercial gill nets (4 inch, stretch measure) showed trends similar to those reported for the impounding nets:

Year	Number measured	Average standard length in millimeters	Average standard deviation in millimeters
1939	1,104	297	28
1940	6,491	289	24
1941	8,994	275	26
1942	311	265	19
1943	531	267	13

TABLE 11.—*Age-group composition of tullibee caught in impounding nets at Lake of the Woods, 1939 to 1943*

Year	Percentage of total catch in age group							
	I	II	III	IV	V	VI	VII	VIII
1939	....	4	13	35	34	11	2	1
1940	....	7	34	23	23	11	1	1
1941	....	37	45	9	7	1	1	....
1942	7	41	48	3	1	....	....	....
1943	1	53	36	7	3	....	....	....

where commercial fishing for ciscoes is carried on, few of the fish are over 4 years old. Apparently, intensive fishing for *Leucichthys artedi* often results in the establishment of populations of young fish.

Discussion

The commercial production of tullibee was fairly uniform in 1941, 1942, and 1943, but it is unlikely that this production is at the level of the highest sustained yield. That the heavy fishing in 1939 and 1940 reduced the population and the breeding stock below the level for maximum yield is indicated by the dependence of the fisheries on 2- and 3-year-old fish in 1941, 1942, and 1943. The annual increment in weight of tullibee increases until the sixth year of life, and during the sixth year the weight increase is more than during the first 3 years of life. Maximum production could probably be secured and maintained if the tullibee were removed in their fifth or sixth year of life.

Maintenance of a high tullibee population in Lake of the Woods may not be a desirable goal. Inspection of tullibee for *Triaenophorus* worms indicated that a marked decline in the incidence of parasitism has accompanied the reduction in the catch from 1939 to 1942. A reduced tullibee population might result in a greater production of parasite-free fish than if the maximum population were maintained.

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THE POSSIBILITIES OF A COMMERCIAL FISHERY IN THE TVA IMPOUNDMENTS AND ITS VALUE IN SOLVING THE SPORT AND ROUGH FISH PROBLEMS[1]

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ABSTRACT

Increased prices and the scarcity of meat have created a much greater demand for fishery products. Meeting this demand will require the fullest utilization of our fresh-water fishery resources because our marine fishery is partly inoperative due to war conditions. It is believed that the fishes produced in the TVA impoundments can make a significant contribution to the food-for-victory program. Investigations conducted on these impoundments during the past 5 years indicate that they are rich in fish life and are capable of supporting an extensive fishery. Although all forms of netting are prohibited, there was an average take of 25 pounds of fish per acre by sport and setline fishermen during 1940 in the four lower reservoirs: Guntersville, Wheeler, Wilson, and Pickwick. This rate of production greatly exceeds the average yield of 1.8 pounds per acre from the Great Lakes.

Fish population studies in the backwaters of Wheeler Reservoir suggest that much larger catches could be made if certain types of gear, such as seines, trap nets, and gill nets, were legalized. These studies revealed populations as high as 831 pounds per acre in waters only 2 to 3 feet deep. The average population per acre for all areas studied was 8,246 fish weighing 576 pounds. Coarse fish were dominant in all the areas and comprised 82.5 per cent of the total weight taken, while game fish comprised only 3.0 per cent, pan fish 9.6 per cent, and food fish 4.9 per cent. This predominance of the coarse species coupled with a decline of the game species indicates that the coarse fishes are increasing at the expense of the game species. A commercial fishery in these waters would be valuable, therefore, not only for furnishing an estimated annual yield of 22 million pounds of fish for which there is a great need during the present emergency, but also for controlling the coarse species.

There are, however, several problems to be solved before a commercial fishery can be established in these reservoirs. Among these problems are the removal of legal restrictions on netting, the development of a market for the coarse species, and the discovery of profitable methods for taking fish. It is hoped that legal restrictions on netting will be removed in the near future by legislative action of the states concerned. Due to the present emergency there is now a market for several of the coarse fishes such as carp and buffalo for which there is a very limited demand during normal times. Those species, such as gar, shad, and mooneye, which are not in demand for food can be utilized along with the offal from the edible fish for the production of fish meal and oil. Experiments conducted to date indicate that their use in this manner is both practicable and profitable. Studies to determine the most feasible fishing methods indicate that fyke nets and gill nets are of limited value for the taking of coarse fish, except in certain localities and at certain times. Large-mesh gill nets are quite effective for several species and are especially good below the dams. Seines

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have to date given the best returns, but their use is restricted to areas free of stumps and other obstructions. While the problem is yet to be solved it is probable that if legal restrictions on netting are removed the fishermen will devise ways and means of taking the fish. It is believed that through the use of several types of gear at different times, or for different species, it will be possible to carry on a profitable commercial fishery in the TVA reservoirs. Such a fishery must be managed, however, so that the even less desirable species, such as gar, shad, and carpsuckers, do not become dominant in the event that carp and buffalo can be controlled.

Introduction

During the Second World War, as during the First, high prices and the scarcity of meat are creating a greater demand for fishery products. Certain conditions now in effect may, however, make it more difficult to meet this demand than it was during the last war. Submarine warfare, the utilization of a large portion of the marine fishing fleet for patrol and other purposes, scarcities of supplies and equipment, and the lack of trained personnel have curtailed the marine fishing operations which have supplied a large portion of our fishery products. Therefore, it will be necessary to depend more on our fresh-water fisheries. With the Great Lakes in their present condition of partial depletion, it is clear that all other bodies of fresh water of any size must be considered and their resources utilized to the fullest possible extent consistent with good management. With the depletion of some of the more valuable species of food fishes in some of our waters we are turning more and more to carp, buffalo, suckers, and other coarse fishes which were formerly considered of little value for food. The increasing value of the rough fishes should permit the development of a commercial fishery for these species in certain rich southern waters where one could not operate successfully in peace time when the more desirable fishes could be purchased at a lower price. Due to an abundance of these coarse fishes it is believed that the impoundments created by the TVA on the Tennessee River can support a fishery and should, therefore, be considered along with the natural waters. Studies of these impoundments, which have been carried on for the past several years, indicate that they can contribute a great deal toward our food-for-victory program. In the Axis countries, Germany and Japan in particular, competent staffs are at work to raise to a maximum the production of carp and other fishes in their artificial impoundments and other inland waters. In this country we have not profited by the experience of Europeans and Orientals; in fact considerable doubt still exists as to the value of artificial impoundments for the sustained production of fish.

A few years ago it was believed by many fishery workers that dams and their impoundments were, as a whole, harmful to the fish population of a river. It was contended that within a year or two after impoundment there was a peak in productivty and fishing was very good,

after which it gradually dropped off and in a few years became poorer than it was in the original stream. The impression that all impoundments went through this cycle and that eventually they all became virtual aquatic deserts was widespread. As a result of this opinion many fishery people felt that Wilson Dam was detrimental from the fishery standpoint and they did not look with favor on the dam-construction program of the TVA which was to change the Tennessee River into a series of relatively quiet pools or lakes. This attitude is understandable because, if this general impression was correct, fishing would be virtually destroyed throughout the entire length of one of the chief tributaries of the Mississippi system.

The creation of Wilson Reservoir in 1924 began this process of impoundment which was taken over by the TVA in 1933 and vigorously extended until there are now 9 main-river reservoirs and 14 storage reservoirs constructed or in the process of construction on the Tennessee River and its tributaries. When completed, these reservoirs will have a combined productive area of about 600,000 acres. Taken as a whole they rank in size after Lake Ontario among the fresh waters of the country. The nine dams on the main stream impound the Tennessee River from a point about 22 miles above its mouth to Knoxville, Tennessee, a distance of 635 miles. These nine reservoirs will have a combined area of 440,000 acres and a shoreline of approximately 6,800 miles. Fluctuations of water level are kept to a minimum and they contain areas of shallow water which should be productive of fish life.

Comparison of Impounded and Unimpounded Sections

Contrary to preconceived notions, the investigations conducted to date indicate that fish populations in these reservoirs are large and that fishing now compares favorably with that found in other parts of the country. Even the oldest reservoir, Wilson, is still maintaining a high level of productivity (Tarzwell, 1941) and fishing in it is reported to be better than it was in the former river both from the standpoint of quality and quantity. Fyke-net studies made simultaneously in Wheeler Reservoir and in unimpounded stretches of the river showed that the fish population was larger in the impounded waters (Smith and Miller, 1943). The average catch per net set in Wheeler Reservoir, which was in its fifth year of impoundment, was about 9 times as great as it was in the main river in what was to become Watts Bar Reservoir, and over 10 times as great as that secured from the Holston River. These fyke-net studies suggested some alteration in the species composition after impoundment, as is to be expected when river conditions are modified to resemble those of a lake. These early changes, however, are on the whole distinctly beneficial as periodic and stratified random counts of fishermen in impounded and unimpounded sections of the river demonstrate that the amount of fishing is many times greater in the former areas (Eschmeyer, 1943; Tarzwell and Miller, 1943).

It might be argued that these reservoirs are still relatively new and

that a decided decline in fish production may still be expected in the next few years. The evidence, however, fails to support this argument. In Wilson Reservoir fishing as a whole is still holding up (in 1942) after 18 years of impoundment. It is believed that the main-stream reservoirs of the Tennessee River will not exhibit a peak of productivity and a decline such as has been reported for the irrigation reservoirs of the arid west because conditions are considerably different. After the closure of an irrigation reservoir all water is stored for a considerable period and the richness caused by the flooding of new soil and terrestrial vegetation is retained for a period of time sufficient to influence fish productivity. After the almost complete removal of this intial water for irrigation, productivity is considerably reduced, and the fish population is, in time, correspondingly reduced. In the more humid Tennesseee Valley, however, stream flow is much greater, and the water in the main-stream reservoirs is changed many times during even the first year of impoundment, as the volume of the reservoirs is small in comparison to the flow through them. Furthermore, the more abundant vegetation in the Tennessee Watershed and the fertilizer, especially phosphates, used on the farm lands of the valley will perhaps be factors in maintaining productivity in the Tennessee River reservoirs. In addition it is believed that the manner in which these reservoirs are operated will exert a considerable influence on fish production.

The TVA reservoirs are multipurpose reservoirs, that is, they are constructed for the purposes of flood control, navigation, power, and national defense. In carrying out these programs the reservoirs are fluctuated in such a way that conditions are better for fish life than they are in those reservoirs used only for power or irrigation. Due to the needs of flood control, drawdowns occur mostly in winter, the non-growing season, rather than in summer as in the irrigation reservoirs. Furthermore, in the run-of-the-river reservoirs the extent of this draw-down is limited by the necessity of maintaining adequate heads for power production. Because these reservoirs are also operated for navigation they cannot be fluctuated widely at any time; for example, fluctuations in Guntersville Reservoir are limited to 2 feet in order to maintain a navigable channel at the upper end of the impoundment. Also, because there is a series of reservoirs time is given for siltation, and the water is much clearer than it was in the former river channel or than it would be if there were only one reservoir. These factors, coupled with stabilization of water levels during most of the spawning season, have contributed to the rapid development of large populations of fish in the reservoirs. Impoundment of a large portion of the Tennessee River has largely eliminated certain aquatic resources such as the mussel beds and has, through changing environmental conditions, greatly reduced the numbers of several stream species, such as rock bass, Kentucky bass, certain of the redhorse, and several minnows. On the other hand, however, many species have in-

creased to such an extent that for some time there have been indications that impoundment has increased the potential value of the fisheries of the Tennessee River several fold.

Extent and Value of the Present Fishery

Because of the apparent increase in productivity subsequent to impoundment, fishery studies conducted during the past three years on the lower, or main-stream, reservoirs have been directed toward the determination of the nature, extent, and value of the present fishery, the potential productive capacity of the reservoirs, and the discovery and testing of means whereby the fish resources can be utilized more fully and yet managed on a sustained-yield basis to the end that both commercial and sport fishing can be maintained. In carrying out this program a census of sport and commercial fishing, an inventory of the amount of fishing, and studies of the fish population were made. Studies were made also with gill nets, setlines, fyke nets, and seines to determine the extent and composition of their catch and their value for a commercial fishery which would not be harmful to sport fishing. Results of the several studies will be discussed separately.

Creel-census studies.—A census of sport fishing on the lower TVA reservoirs was begun in 1939 and has been continued to date. A comparison of the returns from this census for each succeeding year reveals a gradual improvement in the catch per hour and in the average catch per person for all the reservoirs except Guntersville. In Wheeler Reservoir in 1939 the catch per hour was 0.4 fish and the average catch per person was 2.6 fish, while in 1941 the catch per hour was 0.9 fish and the average catch per person was 4.8 fish weighing 3.8 pounds. In Pickwick Reservoir during the same period, the average catch increased from 1.6 fish taken at the rate of 0.3 fish per hour to 6.6 fish weighing 4.5 pounds taken at the rate of 1.2 fish per hour. Fishing in the tailwater areas below the dams has been the best in the Valley and compares favorably with any found in the country. The best fishing was below Wheeler Dam in the tailwater at the upper end of Wilson Reservoir, where in 1940 the average catch was 8.2 fish weighing 7.4 pounds taken at the rate of 1.4 fish per hour.

Improvements in the catch are largely due to the great increase in the numbers of both black and white crappie. Although the catch as a whole has improved, there has been an alarming decrease in the abundance of game fishes, especially black bass, as pointed out by Tarzwell (1941). In Wheeler Reservoir, game fishes comprised 28 per cent of the total catch in 1939, 20 per cent in 1940, and 9 per cent in 1941. Returns from the other reservoirs indicate that the game species are generally declining in the catch. In Wilson Reservoir, game fishes comprised only 3 per cent of the total catch of sport fishermen during 1940 and 1941. These returns suggest a decline in the game-fish population as the reservoirs become older. However, because this decrease has been more than compensated by the increased catch of panfishes,

especially crappie, it cannot be attributed to a decline in productivity. In Wheeler, the reservoir for which the best records are available, panfishes represented 42 per cent of the total catch in 1939, 60 per cent in 1940, and 86 per cent in 1941. Although this great increase in crappie was perhaps a factor in the decrease of game fishes, it is believed that increases in the numbers of coarse fishes are a contributing factor. Because those fishing with rod and reel try to avoid the taking of rough fish, and the bank fishermen do not fish especially for them, the returns from the creel census are not representative of the actual population and do not give an adequate idea of the relative abundance of the coarse fishes.

Census of commercial fishing.—To obtain a better idea of the fish population, the composition of the total catch from the reservoirs, the relative abundance of the different species in the commercial catch, and the value of commercial fishing in the area, the census of commercial fishing which was initiated below Wilson Dam in 1939 was extended to the four lower reservoirs during 1940 (Bryan and Tarzwell, 1941). Because the Stanford Act passed by the Alabama Legislature in 1935 prohibited the use of nets in impoundment waters of the state, commercial fishermen can use only setlines and snaglines for their operations. Contacts with the fishermen during the period of the census indicated a unanimity of opinion that rough fish had increased since impoundment and the prohibition of netting. This position is supported by the fact that setline fishermen caught many carp, although they fished almost exclusively for catfish. During the year of the census it is estimated that over 1,200,000 pounds of fish were taken from the four lower reservoirs by the commercial fishermen.

Inventory of fishing.—Stratified random counts of all fishermen to determine the total amount of fishing in the lower reservoirs were begun in 1940 and continued for a period of a year (Tarzwell and Miller, 1943). These counts indicated that there were over 1,200,000 fisherman-days of fishing on the four lower reservoirs—Guntersville, Wheeler, Wilson, and Pickwick—during the year. Man-days of fishing per acre varied from 6.4 in Wheeler Reservoir to 3.3 in Pickwick, and fishing per mile of shoreline from 566 trips on Wilson Reservoir to 311 on Pickwick. Wheeler Reservoir was the most intensively fished, with 2.2 man-days of boat fishing per acre and 270 bank fishing trips per mile of shoreline. More than 60 per cent of the total number fishing were bank fishermen, who caught mostly coarse fishes. On the basis of the average catch of boat and bank fishermen for each area as determined by the creel census, of the total number of people fishing as denoted by the counts of fishermen, and of the total take of commercial fish as indicated by the census of that fishing, it is estimated that about 5 million pounds of fish were taken from the four lower reservoirs during 1940. This catch represents an average yield of about 25 pounds of fish per acre. Of the three lower reservoirs the smallest take, 15 pounds per acre, was from the youngest reservoir, Pickwick,

which was in its third year of impoundment; and the largest yield, 32 pounds per acre, was from the oldest reservoir, Wilson, which was in its sixteenth year of impoundment. The total yield of the Great Lakes for 1939, as reported by Fiedler (1942) indicates an average yield per acre of 1.8 pounds for those waters. The richest of the lakes, Erie, had a yield of about 6.7 pounds per acre in 1931. When these yields are compared with that from Wilson Reservoir, it is clear that some impoundments are capable of maintaining a high level of productivity over considerable periods.

The fact that the largest yield per acre was secured from Wilson, the oldest reservoir, tends to refute the idea that the productivity of all impoundments declines as they become older. In view of this and other evidence brought out by the census of sport and commercial fishing and by the fish population studies, it is concluded, as pointed out by Tarzwell (1941), that the decline in sport fishing is due to a change in the species composition of the fish population rather than to a decline in total productivity. Such a shift in species, with replacement of the more valuable fishes by the less valuable ones, is to be expected when the desirable game species are taken in large numbers throughout the year while the coarse fishes are more or less protected by the prohibition of netting. This change in species composition is well illustrated by conditions in Wilson Reservoir where sport fishing has become poorer since all forms of netting for the coarse fishes were prohibited in 1936. During 1940 and 1941, game fishes comprised only 3.0 per cent of the total sport catch in Wilson Reservoir.

That this shift in species composition may now be taking place in the younger reservoirs is suggested by the decline in the proportion of game fishes in the catch. This condition is strikingly illustrated by the creel-census returns from Wheeler Reservoir between 1939 and 1941 when the proportion of game fishes dropped from 28 to 9 per cent. If such trends exist it is important that they be detected as soon as possible in order that they may be arrested by some control of the coarse fishes. Fish population studies to determine the relative abundance of the various species in the standing population from year to year offer one of the best means for detecting such trends.

Fish population studies.—Studies of the total fish population were begun in the backwaters of Wheeler Reservoir in 1941. These investigations were made in selected areas which were shut off from the main reservoir by means of a barrier seine and treated with rotenone to remove the fish. The barrier seine, which was made by fastening lead and float lines to a strip of sheeting that had been treated with paraffin and linseed oil to make it impervious to water, retained the fish in the area and prevented the spread of rotenone to other areas. Five backwater areas of Wheeler Reservoir were studied in this way between the latter part of May and the end of September. These plots which had a combined area of about 34.3 acres and a volume of slightly over 77 acre feet are fairly representative of the backwaters of Middle

Wheeler Reservoir. A total of 282,852 fish, exclusive of *Gambusia* and brook silversides, weighing 19,765 pounds was taken from these 34.3 acres. The excluded fish were very numerous but could not be picked up as they sank to the bottom and decomposed without coming to the surface. The average fish population per acre for the five areas as a whole was found to be 8,246 fish weighing 576 pounds. On this same basis there was an average of 8.3 legal-sized game fish weighing 10.2 pounds and 125 legal-size panfish weighing 19.3 pounds per acre of water surface. When each area was given equal weight regardless of size or depth, by combining the number and weight of fish per surface acre from each plot, the average per acre was 13,215 fish weighing 501 pounds. The larger number and smaller weight per acre secured by this method is due to the fact there is a concentration of small fishes in the shoal areas. As only the largest plot, Middle Railroad Pond, had a depth greater than 4 feet, giving each area equal weight tends to make the average more representative of the shallow waters. The average population per acre foot of water obtained by giving each area equal wieght was 10,141 fish weighing 311 pounds. The average population per acre foot of water for the five areas as a whole was 3,667 fish weighing 256 pounds. These latter figures are probably more representative of the average population per acre foot of water in the backwaters because the larger more typical area is given more weight. In Table 1 the areas studied and their fish populations are compared. The relatively small numbers of fish secured from Upper Railroad Pond in May and from Sweetwater Slough in June are due in part to the fact the pan fishes had not yet spawned or the fry were too small to be collected and counted. A comparison of the populations found in those five areas suggests that the shallow protected areas of the backwaters are mainly nurseries for the sunfishes. However, when these areas are compared on the basis of volume of water, the shallow flats contain more legal game and pan fishes than the deeper areas, indicating that even the very shallow areas are productive. On the basis of area alone, food and coarse fishes are relatively more abundant in the deeper portions of the backwaters. All areas had large populations, and those averaging 2 to 3 feet deep had populations ranking with the largest which have been reported to date (Tarzwell, 1940). The sizes of these fish populations are well illustrated by the fact that although the legal pan and game fishes represented only a small part (5.5 per cent) of the total weight of fish per acre in Middle Railroad Pond they weighed 43.4 pounds or more than the total fish population found in some northern lakes (Smith, 1935 and 1938; Eschmeyer, 1938).

Coarse fishes comprised a very large percentage of the total weight of fish taken in all areas. The relative abundance of game, pan, food, and coarse fishes in each of the areas studied is shown in Table 2. The fact that the coarse species made up 82.5 per cent of all fish taken in the five areas clearly shows the dominance of that group. The numbers and weights of each species per acre from Upper and Middle Railroad

TABLE 1.—*A comparison of the areas of Wheeler Reservoir studied and their fish populations*

Item	Upper Railroad Pond	Upper Railroad Pond	Sweetwater Slough	Powerline Slough	Middle Railroad Pond
Date treated	May 28, 1941	September 23, 1941	June 4, 1941	August 5, 1941	September 23, 1941
Area (acres)	6.5	3.3	4.38	1.1	18.97
Maximum depth (feet)	3.0	2.5	1.5	3.0	7.0
Average depth (feet)	0.9	0.8	1.0	2.4	3.2
Volume of water (acre feet)	5.75	2.85	4.40	2.69	61.44
Type of bottom	Soft clay mud	Soft clay mud	Silt and some debris	Firm clay	Clay mud and silt
Water temperature (°F.)	84	88	86	94	86
Concentration of rotenone (p.p.m.)	0.10	0.38	0.08	0.17	0.09
Number of fish taken	17,641	71,272	10,160	23,024	160,755
Weight[1] of fish taken	1,896	1,128	828	914	14,999
Number of fish per acre	2,714	21,597	2,309	20,933	8,474
Weight of fish per acre	292	342	188	831	791
Number of fish per acre foot	3,068	25,008	2,309	8,559	2,616
Weight of fish per acre foot	330	396	188	340	244
Number of legal game fish per surface acre	7.7	10.6	0.5	14.5	9.4
Number of legal game fish per acre foot	8.7	12.3	0.5	5.9	2.9
Weight of legal game fish per surface acre	6.2	13.9	0.5	10.4	12.7
Weight of legal game fish per acre foot	7.0	17.4	0.5	4.2	3.9
Number of legal pan fish per surface acre	....	....	....	57.2	197.0
Number of legal pan fish per acre foot	....	....	....	23.3	60.7
Weight of legal pan fish per surface acre	....	13.2	....	10.7	30.7
Weight of legal pan fish per acre foot	....	15.2	....	4.3	9.4

[1]All weights in pounds.

TABLE 2.—*Abundance of game, pan, food, and coarse fishes in the five areas treated with rotenone and in the fyke-net and seine catches expressed as their percentage of the total number and weight of fish taken.*

	Game fish		Panfish		Food fish		Coarse fish	
	Number	Weight	Number	Weight	Number	Weight	Number	Weight
Upper Railroad Pond[1]	29.7	3.9	27.9	6.7	1.2	4.1	41.0	85.2
Upper Railroad Pond[2]	0.4	7.3	93.4	31.6	0.3	2.1	5.9	59.0
Sweetwater Slough	4.0	2.3	71.9	19.2	5.2	5.9	18.9	72.6
Powerline Slough	2.0	3.3	59.5	9.4	0.8	3.0	37.6	84.3
Middle Railroad Pond	0.9	2.5	50.6	7.8	1.3	5.3	47.3	84.4
Average all acres combined	2.8	3.0	61.6	9.6	1.1	4.9	34.5	82.5
Weighted average per surface acre	2.3	3.5	71.9	13.0	0.8	3.9	25.1	79.6
Weighted average per acre-foot of water	2.6	4.1	79.6	17.3	0.7	3.6	17.2	75.1
Fyke-net catch	3.2	5.6	81.4	49.6	3.7	19.9	11.7	24.9
Seine catch	2.3	3.1	7.2	2.8	18.2	13.3	72.4	80.8

[1]Poison applied in May.
[2]Poison applied in September.

Ponds are shown in Table 3, as well as the percentage of the total number and weight which each species comprised of all fish taken in the five areas. The number and weight per acre of the undersized and fingerling black bass and pan fishes are also shown. These figures indicate that natural reproduction of sunfishes in these areas, especially in Upper Railroad Pond, is very successful. After the fish in this area were poisoned in late May, all fish were excluded until July 10. Therefore all fingerling sunfishes taken in the area in September were either produced there after July 10 or migrated in from Middle Railroad Pond. As Upper Railroad Pond had over 19,700 fingerling sunfish per acre and only 71 legal sunfish the ratio of fingerlings to legal-sized fish was 277:1. In Powerline Slough in August the ratio was 253:1 and the weighted average for all areas studied gave a ratio for all sunfishes of 142:1. These figures seem to indicate that natural reproduction is sufficient for all purposes and that huge stockings would be required to increase even slightly the number of legal sunfishes per acre.

Even assuming that the addition of more fish would not increase this survival ratio of 142:1 and that they would survive as well as the natural spawn, it would require a planting of over 126 million fingerlings to increase the number of legal-sized sunfish 10 per cent in Wheeler Reservoir. In bodies of water the size of Wheeler Reservoir it is believed that artificial stocking cannot materially increase the number of legal sunfish as the population is now large and the addition of large numbers of fingerlings would probably increase the natural ratio of fingerlings to legal fish. The same principle applies for the crappie. Although crappie were not taken in large numbers in the population studies due to the fact they migrate to deep water in the summer months, their rapid increase in the catch is ample evidence of their great reproductive capacity.

As indicated in Table 2, game fishes made up a larger portion of the total population in Upper Railroad Pond in May than they did in

TABLE 3.—*A comparison of the fish population of the backwaters of Middle Wheeler Reservoir with the catch of fyke nets and seines. "Population studies" refers to investigations in which all fish were poisoned and removed.*

Species	Fish population studies: Number and pounds of fish per acre: Upper Railroad Pond Number	Upper Railroad Pond Weight	Middle Railroad Pond Number	Middle Railroad Pond Weight	Relative abundance of each species expressed as a percentage of the total take: Middle Railroad Pond: Population studies Number	Population studies Weight	Fyke-net catch Number	Fyke-net catch Weight	Middle Wheeler Reservoir: All population studies Number	All population studies Weight	145 fyke-net catches Number	145 fyke-net catches Weight	Middle and lower Wheeler: 92 seine hauls Number	92 seine hauls Weight
Lepisosteus productus	24.2	20.6	38.1	76.5	0.5	9.7	1.7	10.7	0.4	8.5	1.5	7.3	0.3	1.[illegible]
Lepisosteus osseus oxyurus	......	......	trace	0.1	....	0.0	....	....	....	....	0.3	1.1	0.0	0.1
Amia calva	0.9	1.4	2.0	5.8	0.0	0.7	0.1	0.3	0.0	0.6	0.0	0.1	0.1	0.7
Amphiodon alosoides	......	......	......	......	....	....	....	....	....	....	0.0	0.1	0.0	0.0
Pomolobus chrysochloris	......	......	0.5	trace	....	....	....	....	0.0	0.0	0.0	0.0	0.4	0.3
Dorosoma cepedianum	1,130.3	126.4	3,390.8	203.5	40.0	25.7	5.2	5.3	28.6	27.2	4.2	2.9	47.5	26.[illegible]
Megastomatobus cyprinella	......	......	73.2	101.6	0.9	12.9	0.2	1.3	0.5	10.1	0.1	0.7	1.0	7.[illegible]
Ictiobus niger	16.1	7.5	75.1	37.4	0.9	4.7	0.8	1.8	0.6	4.1	0.4	0.7	1.8	4.[illegible]
Ictiobus bubalus	17.6	9.0	142.3	82.6	1.7	10.5	1.9	4.6	1.0	8.1	2.7	4.0	14.7	22.4
Carpiodes	......	......	2.4	1.3	0.0	0.2	0.3	1.1	0.0	0.2	0.2	0.7	3.0	8.0
All Catostomidae	47.0	21.5	293.7	223.2	3.5	28.3	4.1	11.1	2.4	24.4	4.3	7.7	20.7	42.5
Cyprinus carpio	43.9	31.6	197.0	157.8	2.3	20.0	0.5	1.2	2.3	21.6	1.3	5.7	3.4	9.3
Other Cyprinidae	63.6	0.3	54.7	0.1	0.7	0.0	....	....	0.9	0.0	....	....	0.0	....
Ictalurus and *Pilodictis*	......	......	6.4	7.5	0.1	0.9	0.2	0.2	0.1	0.7	1.2	17.3	2.9	5.2
Ameiurus	47.6	5.2	70.3	24.3	0.8	3.1	4.6	6.7	0.8	3.0	2.0	2.2	0.5	0.6
Esox niger crassus	......	......	trace	trace	....	0.0	0.3	2.0	....	0.0	0.2	0.9	0.0	0.1
Lepibema chrysops	10.9	2.0	20.3	1.6	0.2	0.2	0.8	1.5	0.2	0.2	2.4	3.3	1.3	1.0
Morone interrupta	3.9	1.0	9.9	1.0	0.1	0.1	....	....	0.1	0.1	0.2	0.1	0.2	0.1
All Serranidae	14.8	3.0	30.2	2.6	0.4	0.3	0.8	1.5	0.2	0.3	2.6	3.4	1.5	1.1
Stizostedion c. canadense	......	......	......	......	....	....	....	....	....	....	0.0	0.1	....	....
Micropterus p. punctulatus	......	......	......	......	....	....	....	....	....	....	0.1	0.3	....	....
Huro salmoides—legal	10.6	13.9	9.4	12.7	0.1	1.6	0.1	0.6	0.1	1.8	0.3	0.9	....	....
Huro salmoides—undersized	5.5	2.8	9.2	3.6	0.1	0.5	....	....	0.2	0.6	....	....	....	....
Huro salmoides—fingerlings	55.5	4.3	24.3	1.3	0.3	0.2	....	....	2.2	0.3	....	....	....	....
All black bass	71.5	22.1	42.9	17.6	0.5	2.2	0.1	0.6	2.5	2.7	0.4	1.2	0.8	1.9
Chaenobryttus gulosus—legal	0.3	0.1	1.6	0.2	0.0	0.0	....	....	0.0	0.0	0.2	0.1	....	....
Chaenobryttus gulosus—undersized	13.0	0.4	34.9	1.5	0.4	0.2	....	....	0.4	0.2	....	....	0.0	....
Chaenobryttus gulosus—fingerlings	331.5	2.1	28.4	0.2	0.3	0.0	....	....	0.6	0.1	....	....	....	....
Lepomis cyanellus—legal	......	......	0.1	trace	....	....	....	....	....	0.0	0.1	0.1	....	....
Lepomis cyanellus—undersized	57.3	1.3	8.1	0.2	0.1	0.0	....	....	0.4	0.1	....	....	0.0	....
Lepomis cyanellus—fingerlings	49.1	0.3	59.8	0.2	0.7	0.0	....	....	0.5	0.0	....	....	....	....
Lepomis humilis—adult	137.0	0.5	0.8	trace	0.0	....	....	....	0.5	0.1	....	....	0.2	....
Lepomis humilis—fingerlings	1,054.5	1.9	357.6	0.8	4.2	0.1	....	....	3.8	0.1	....	....	....	....
Lepomis megalotis	......	......	......	......	....	....	....	....	....	....	0.1	0.1	....	....
Lepomis m. macrochirus—legal	64.5	9.0	147.5	15.6	1.7	2.0	12.3	7.5	1.1	1.8	13.0	5.9	1.9	0.5
Lepomis m. macrochirus—undersized	50.6	1.2	164.0	5.1	1.9	0.6	....	....	3.7	1.4	....	....	....	....
L. macrochirus and *microlophus*—fingerlings	18,282.4	78.2	3,182.1	5.5	37.6	0.7	....	....	47.2	2.0	....	....	....	....
Lepomis microlophus—legal	6.4	0.6	7.2	0.8	0.1	0.1	0.6	0.3	0.1	0.1	0.5	0.2	0.7	0.1
Lepomis microlophus—undersized	7.0	0.3	13.2	0.2	0.2	0.0	....	....	1.2	0.3	....	....	....	....
Pomoxis nigro maculatus	3.9	1.0	53.8	9.2	0.6	1.2	23.9	25.4	0.4	1.0	24.2	16.3	0.5	0.3
Pomoxis annularis	87.0	11.4	258.1	21.9	3.0	2.8	45.6	27.4	1.9	2.5	43.6	27.0	4.0	2.0
All *Pomoxis*	90.9	12.4	311.9	31.1	3.7	3.9	69.5	52.8	2.3	3.5	67.8	43.3	4.5	2.2
Aplodinotus grunniens	9.1	1.8	30.3	10.1	0.4	1.3	....	....	0.3	1.2	0.5	0.4	14.9	7.6

any other area. This situation was due to the large number of naturally spawned "No. 2" fingerling largemouth black bass which averaged some 785 per acre and were in a ratio to legal bass of over 100:1. As the season advanced, and the size of the young bass of the year increased, this ratio decreased rapidly, indicating a considerable mortality. In September the ratio in this same area was 10:1. In June, at Sweetwater, the ratio was 90:1, in August, at Powerline Slough, it was 24:1; and in late September, at Middle Railroad Pond, it was 3:1 where the undersized or yearling bass numbered about the same as the legal bass. These ratios show a large mortality and indicate that materially increasing the numbers of legal bass by stocking fingerlings after the fish population has become established in the reservoirs is practically impossible. Natural propagation would be more than adequate if it were not for the high mortality which accompanies a high population pressure.

In each of the lower reservoirs there has been a relatively large and successful hatch of bass the first year of impoundment when the population pressure of other fish was low. It is believed that the most effective procedure for the stocking of black bass in the reservoirs is to plant legal-sized bass the year prior to impoundment. If successful this method would provide large numbers of spawners for the first spawning season, and a huge hatch of bass should be produced. In this way it might be possible to secure enough bass so that they can become dominant and control the coarse species or at least delay their dominance (increase). Stabilization of water levels during and for a few weeks after the spawning season is a measure which may be quite effective for increasing the numbers of game fishes and of some pan fishes. Stable water levels in Wilson Reservoir during the spawning season of 1939 were credited by local fishermen for the improvement in crappie fishing on the reservoir in the fall of 1940 and for the even greater improvement in 1941. In 1940 crappie comprised 59 per cent of the total sport catch in Wilson Reservoir and in 1941 they made up 90 per cent. It may be that water-level stabilization during the spawning season which was begun in 1939 is a factor in the improvement of crappie fishing throughout the lower reservoirs.

Food fishes, the catfish and drum (sheepshead), were not very abundant in any of the areas studied. The large individuals of these species generally remain in the deep water of the old river channel, as do most of the large carp and buffalo. However, large numbers of the medium-sized individuals of these latter species remain in the backwaters and together with gizzard shad and gar comprise practically the total weight of coarse fishes in those areas. As shown in Table 2 the coarse fishes made up the greater part of the total weight of fish taken in all the areas treated with poison. These large, coarse-fish populations, combined with the decrease of game fishes in the catch as shown by the creel census, suggest that there is a shift in species in Wheeler Reservoir from the more valuable game fishes to the coarse fishes which shift,

if not arrested and reversed, is likely to reduce sport fishing to the level now found in Wilson Reservoirs.

Although this dominance of the coarse fishes is due in part to the fact that environmental conditions are more favorable for them, it is certainly encouraged by the unbalanced fishery now being practiced in these impoundments. Because almost everyone prefers to catch the more desirable game species, particularly black bass, fishing for them was very heavy and was especially so just before and during the critical spawning period, as there was no closed season in Alabama prior to 1943. Conversely, however, the coarse fishes are not desired by the sport fishermen and they are more or less protected from commercial fishing by the prohibition of all forms of netting in the impounded waters.

On the basis of the composition and average weight of the catch of bank and boat fishermen as shown by the creel census, the amount of fishing per acre as indicated by the inventory of fishing, and the total population as shown by the population studies, it is estimated that bank and boat fishermen annually take about 45 per cent of the legal game fishes, 25 per cent of the legal pan fishes, and 6 and 2 per cent, respectively, of the usable food and coarse fishes.

Under such conditions it is to be expected that the coarse species will increase at the expense of the game species. It is not necessary for the coarse species to eat the game fishes in order to reduce their numbers. Their intense competition with the young of the game species for food and space, coupled with their much greater reproductive powers and an environment which favors them, is sufficient to reduce greatly the young of the game species. Such a reduction has occurred in the areas studied. This principle is well known to those acquainted with grazing practices, as it is common knowledge that although goats are not predatory on cows, very little beef can be produced in a pasture where goats are abundant. This is especially true if the pasture is more favorable for the goats. The unbalanced fishery in the reservoirs is similar to conditions in a carrot patch from which we take the largest and best carrots while actually encouraging the weeds by exercising no control over them. In time there will be few carrots and the weeds will have so monopolized all space, even that from which the carrots are pulled, that it will be difficult to re-established carrots, and those we do succeed in getting started will probably be of an undesirable size and quality. Thus, whether it be gardening or aquiculture, good management would consist of encouraging in all possible ways the desired and more valuable forms while controlling by all means at hand the less desirable forms. Some methods of encouraging the game species are: closed seasons, stabilized water levels during spawning seasons and for some time thereafter, and the planting of adult fish previous to impoundment. Although varying the water level previous to the spawning season of the black bass may be a means of destroying the spawn of the carp, this practice will not entirely

control them due to their prolonged spawning season. Carp have been known to spawn as late as July (Tarzwell, 1941). It is felt that the establishment of a commercial fishery will assist materially in the control of the coarse fishes.

Possibilities of a Commercial Fishery

The fish population studies which have been made in Middle Wheeler Reservoir show that the coarse fishes are capable of supporting a large fishery. In Middle Railroad Pond, which is considered to be fairly representative of the backwaters of Wheeler Reservoir, there were, for each surface acre, about 77 pounds of gar, 6 pounds of dogfish, 203 pounds of gizzard shad, 222 pounds of buffalo, 158 pounds of carp, 32 pounds of catfish, and 10 pounds of drum, or a total of 708 pounds of fish. As gar, shad, and the small individuals of the other species are not considered suitable for food, only about 428 pounds of this total could be marketed for human consumption. In Powerline Slough, which had an average depth of 2 feet and a maximum depth of 3 feet, there were per acre, 21 pounds of gar, 3 pounds of dogfish, 301 pounds of gizzard shad, 133 pounds of buffalo, 11 pounds of carpsuckers, 222 pounds of carp, 3 pounds of catfish, and 22 pounds of drum, or a total of 723 pounds of coarse and food fish, of which 375 pounds were marketable. Due to the rapid growth of the fishes in these waters, it is believed that about one-third of the total marketable population of coarse and food fishes could be taken each year without depleting the fishery. This would be an annual take of 100 pounds or more per acre from the backwaters of Wheeler Reservoir. As practically all of the large fish are in the deeper waters it is believed that a similar amount could be taken from these areas. This belief is borne out by a take of over 600,000 pounds of spoonbill from Wilson Reservoir in a period of 11 months (Bryan, 1942). This catch represents a yield of 39 pounds per acre for this species alone. As all the lower reservoirs are quite similar, they should have a yield approaching that of Wheeler Reservoir. However, since many areas can be fished only with difficulty, it is believed that a conservative estimate of a sustained yield for the lower reservoirs would be 50 pounds per acre. If this yield could be realized, the lower reservoirs would support an annual fishery of about 22 million pounds. If gar and gizzard shad could be utilized commercially the total yield would be about 50 per cent greater.

Although the TVA impoundments are apparently capable of supporting a commercial fishery of considerable size, and such a fishery would appear to be beneficial to sport fishing by reducing the abundance of the coarse fishes in the area, the establishment of this fishery is beset with certain difficulties. These are: legal restrictions which hamper commercial fishing; the lack of a suitable market for certain species; and the difficulty of finding effective methods for taking the coarse fishes, especially in the stumpy areas. The legal restrictions may perhaps be eliminated by the states in the near future. It is

hoped that methods may be developed for the processing and use of many of the fishes which are at present going to waste. Work of this nature is now being carried on by the TVA Commerce Department. Smoking experiments are being conducted to determine if better methods can be found for processing carp, buffalo, and carpsuckers. Pressure cooking and canning of carp has been carried on with some success. The canned carp compares favorably with salmon when used for fish cakes and salad. However, at the present time the scarcity of meat and high prices have created markets for carp and buffalo which will without doubt continue during the present emergency. In addition the spoonbill are now being utilized on a large scale, and the demand for catfish is greater than the supply which can be furnished by the fishing methods now allowed. It is probable that carp and buffalo could be disposed of in certain of the larger cities if they could be taken regularly and in large numbers so they could be shipped economically.

There is, at present, very little demand for the gar and no demand for the shad for human consumption. However, if all types of netting were legalized it is probable that these fishes would be taken in considerable numbers. It seems desirable, therefore, to determine if some use can be found for these fishes which would at least pay for the handling of those taken along with the more valuable species. Furthermore, it is essential that gar and shad be taken along with the other species in about their relative abundance in the fish population, for if they are not their numbers are likely to increase to such an extent that they will eventually dominate the total fish population. Such an occurrence would be very unfortunate for both the commercial and sport fishery, and would in fact defeat the purpose for which a commercial fishery is envisioned.

With these facts in mind, experiments were conducted to test the value of these fishes and the offal from the food fishes, for the manufacture of fish meal and oil. Some 7,000 pounds of fish were processed in two experimental runs. For each 100 pounds of fish and fish waste there were secured 13 pounds of fish meal and 15 pounds of oil. The fish meal had a protein content of about 55 per cent, a high mineral content, and compared favorably with fish meals made in other parts of the country. The oil was clear and of good quality. As there is at present a local shortage of fish meal as a protein supplement for poultry feed, and as the oil is badly needed in the war effort there is a ready market for these products. It is believed all gar, shad, and fish offal taken by a commercial fishery in these reservoirs could be used in this way. Such use would be an aid to the war effort, would benefit the commercial fishermen by cutting down their overhead cost occasioned by the handling of these fish and disposing of their waste, and would benefit both commercial and sport fishing by promoting the control of gar and shad.

Evaluation of Commercial Fishing Methods

Several types of fishing gear have been used experimentally in the main-river reservoirs to determine their value for commercial fishing under local conditions and to learn the composition of the catches taken by each. It has been found that each type is somewhat selective for certain species of fish and that their total take is largely determined by the season and the location in which they are used. In order to be effective for the control of these coarse species a gear must be somewhat selective for the rough fishes and take them in a greater rlative proportion than they occur in the fish population.

Setlines, which are at present the only legal gear for commercial fishing in the reservoirs in Alabama, have been somewhat selective for the catfishes. Rough fishes can be taken, however, by the use of certain baits. When dough balls are used the coarse species usually comprise more than half of the total take. The total catch by this method, however, is so small that setlines cannot be considered for the control of the coarse fishes. Snaglines, which are similar to setlines, and differ from them in that the hooks are sharpened and are hung along the main line at intervals of about 8 inches, have proven very successful for the taking of spoonbill. These lines are set at varying depths depending upon where the fish are feeding. The fish are caught by snagging themselves when they run into the hooks. The snagline fishery for spoonbill now in operation throughout the lower reservoirs has an annual yield of about a million pounds.

Gill nets have been used in the reservoirs with varying degrees of success. The size of mesh and the depth and location of the set greatly influence the total take and its species composition. Small-mesh nets take many pan fishes and when set near the surface are very selective for gar (Tarzwell, 1941). Larger-mesh nets have been only fairly successful for the taking of coarse fishes in the reserviors. When they are set in the tailwater areas below the dams they have taken large numbers of fish, many of which were of the coarse species. Dr. Van Oosten states that in the Green Bay area of Lake Michigan gill nets of 6- or 7-inch mesh, stretched measure, have been successfully used for the taking of carp without the destruction of game fishes. Their successful use has also been reported by Apel (1942). When set in certain areas of the reservoir large-mesh gill nets would be valuable for commercial fishing, even though they are not selective for certain of the coarse fishes such as carp. They are especially effective when set across tributary streams or ditches leading into the backwaters and in the tailwaters below the dams.

Fyke or hoop nets, having a stretched mesh of 3 inches and a $4\frac{1}{2}$-foot front hoop, were used extensively in Wheeler Reservoir in 1941 (Miller, 1944). In addition to the regular netting 56 sets were made in Middle Railroad Pond prior to the poisoning of the area so that the composition of the fyke-net catch could be compared with the actual

fish population. The relative abundance and weight of the different species in the fyke-net catches and in the fish population of Middle Railroad Pond are compared in Table 3. The fyke net proved to be selective for crappie, which were about 19 times as abundant in the average catch as they were in the total fish population. Bluegills were also several times as abundant in the catch as they were in the population, but almost all the coarse fishes, especially the gizzard shad, buffalo, and carp, were less abundant. When the relative abundance of the various species in the total fyke-net catch from Middle Wheeler (Miller, 1944) is compared (Table 3) with the relative abundance of the different species in the total population from the five areas which were treated with poison, the same relationship is found; that is, there is a great selectivity for crappie, bluegills, and white bass, while the coarse fishes are not as abundant in the catch as they are in the fish population. The relative abundance of the game, pan, food, and coarse fishes in the fyke-net catch from Middle Wheeler is shown in Table 2. When compared with the relative abundance of each of these groups (Table 2) in the total fish population, as denoted by the population studies, the selectivity for game and pan fishes and the small take of the coarse species are evident. These results indicate that in general fyke nets would not be of much value for reducing the coarse fish population. In addition, in most areas of the reservoirs their catch is too small for them to be used with great success in commercial fishing.

In an effort to overcome these difficulties an experiment was conducted to determine if the fyke nets took more fish and a higher percentage of coarse fishes when they were fished with long wings or leads. In Middle Wheeler Reservoir the average catch per set without wings was 15.9 fish wighing 4.6 pounds, while with wings it was 23.7 fish weighing 9.2 pounds. In Lower Wheeler Reservoir the average catch without wings was 9.5 fish weighing 3.3 pounds, and with wings it was 18.5 fish weighing 5.5 pounds. The relative abundance of the different species in the catch was not greatly changed. However, the gizzard shad were over twice as abundant and there were a few more long-nosed gar and drum.

It is probable, however, that larger nets having a 6- to 8-inch stretched mesh would be more successful for the taking of coarse fishes—especially if they were set across tributary streams or the openings through which the water passes into and out of the backwaters. When set in these places such fyke nets should make good catches of the coarse species, as these fish move into and out of the backwaters in large numbers as the water levels in the reservoirs rise and fall. Because the reservoirs fluctuate almost continuously fkye nets could be used profitably for commercial fishing in these limited areas.

Seining operations carried out during the summer of 1938 suggested that this method of fishing was not selective for game or pan fishes and took all fishes in numbers which approached their relative abundance

in the fish population. Seining has been the most successful of the methods tried to date for the taking of carp. This result is in agreement with the findings of Cole (1905). During the summer of 1942, extensive seining operations were carried on to test the value of seines for commercial fishing and to determine the relative abundance of the different species in the catch. The lengths of the seines used in the study varied from 300 to 825 feet and the depths from 8 to 10 feet. The meshes were from 1 inch to 1½ inches bar measure. A total of 92 seine hauls were made in Middle and Lower Wheeler Reservoir from May to August 1942. The longer seines were much more effective for the taking of fish. The average catch with the 825-foot seine was 130 pounds in the Elk River area. While coarse fish comprised about 81 per cent of the weight of the total catch from all areas, only a fourth of the fish taken were coarse fish of marketable size. It is believed that a deeper seine of larger mesh would take many more fish of marketable size, as it would permit seining in the deeper waters where most of the large fishes stay during the summer months. In addition it would allow most of the game and pan fishes to escape. The relative abundance of the game, pan, food, and coarse fishes in the 92 seine hauls is shown in Table 2. The percentage which each species comprised of the total number and weight of fish taken in all the hauls is shown in Table 3. When the abundance of the various species in the catch secured by seining is compared with the composition of the fkyenet catches and the actual fish population as determined by the population studies, Table 2, it is noted that seining is more effective than the fyke nets for the taking of coarse fishes and that the percentage of these fishes in the catch compares favorably with their abundance in the fish population. It is therefore concluded that seining is a feasible and desirable method for commercial fishing in the lower reservoirs in the areas where it can be carried out. The greatest hindrance to such a fishery, however, is the stumpy nature of the backwaters which limits this type of fishing to certain cleared areas. If seining were permitted, it is believed that the fishermen would find ways and means for clearing many areas for seining. Furthermore, the removal of certain legal restrictions would make it desirable for fishermen to clear many areas for seining prior to impoundment, and thus greatly reduce the cost of such operations.

Several types of gear have not yet been tried on the reservoirs, and their practicability and success when used on these waters are, therefore, not known. Among these gears may be listed trammel nets, otter trawls, purse seines, and the typical Great Lakes trap net.

Although an entirely satisfactory method for commercial fishing in the TVA impoundments has not yet been developed, enough has been done to indicate that if restrictions on netting are removed the fishermen can probably develop a commercially practicable method for taking the coarse species. Because considerable experimentation will be required, and as the fishermen will probably have to operate the differ-

ent types of gear for the different species at different seasons and under a variety of conditions, the legislation permitting netting should be liberal and legalize all types of gear. The state conservation commissions, however, should be given discretionary powers to determine the type of gear and size of mesh to be used as well as when and where each gear shall be used. In this way problems and new conditions can be met as they arise and effective management obtained. After the program has been in operation for a time it will be possible to select the fishing methods most effective for the control of the different rough fishes and least harmful to the game species. Although large-mesh nets are often desirable for allowing the game and pan fishes to escape it would not be good management to use such large meshes that gar and gizzard shad are not taken. These fishes must be taken along with the other coarse species, even though some game and pan fishes are also taken, as otherwise they will tend to become dominant and the reservoirs will be populated with fishes even less valuable than the carp or buffalo. There are also indications that some of the pan fishes should be controlled by netting.

As the game fish are generally declining in the reservoirs it would be desirable to initiate a commercial fishery for the coarse species as soon as possible. Although the rough fishes might not be entirely controlled by such a fishery, even partial control should be of benefit in maintaining sport fishing through the reduction of competition for food and space. It is also especially important that a commercial fishery be allowed during the present emergency as it would make available several million pounds of protein food which is not now being utilized. In view of meat rationing these fish would be important, at least locally in the food-for-victory program. As pointed out by Wiebe (1942) this wartime exploitation of our fish crop would be definitely beneficial in several ways.

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Summary

1. The chain of reservoirs created in the Tennessee River by the TVA can make a significant contribution to the food-for-victory program by providing several million pounds of much needed fishery products.

2. The productivity of the TVA impoundments does not appear to have decreased during the past several years and they are now more productive than most of our inland waters and are many times as productive as the Great Lakes on an area basis.

3. Investigations conducted to date indicate the following: that rough fish have been increasing at the expense of the other species in the reservoir; that sport fishing has declined with the increase in the rough fishes; that the present fishery is unbalanced as the game and pan fishes are heavily exploited while only a very small percentage of the coarse fishes are taken; that setlines and snaglines, the only types of commercial gear allowed in the reservoirs, are inadequate to control the coarse fishes; that several million pounds of fish that could be used are going to waste each year; that over five times the present catch of coarse fishes could be taken each year without injury to the fishery; and that netting for the coarse fishes would be beneficial as it would permit the utilization of many of the coarse fishes for food during the present emergency and would benefit sport fishing by exercising some control over the competing coarse species.

4. Although experiments conducted to date have not disclosed a completely satisfactory method for the taking of food and coarse fishes from the impoundments, enough has been done to indicate that if all forms of netting are permitted the fishermen can develop a profitable commercial fishery.

5. All netting should be under the direction of the state conservation commissions, which should have discretionary powers so that all problems can be met and the fishery adequately managed.

6. To provide food for the war effort, to protect the sport fishery, and to utilize the present market for the coarse species which has been created by the war, it is desirable that the commercial fishery on TVA main-stream reservoirs be expanded immediately.

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RESULTS FROM PLANTINGS OF TAGGED TROUT IN SPRING CREEK, PENNSYLVANIA[1]

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Abstract

Data on anglers' catches, the growth and migration of stocked trout, and the efficiency of fall and spring plantings were obtained by means of a creel census in Spring Creek, Pennsylvania, during 1939. Of 2,130 tagged trout planted, 50.8 per cent were recovered by anglers. Due to heavy fishing pressure, more than 40 per cent of all tagged trout taken during the entire season were removed on the first day. A high first-day kill (76 per cent of the total recoveries) of brook trout was noted. The quality of fishing declined rapidly during the early season. Fishing for brook trout was good for only a few days, brown trout fishing was fair for about a month, while rainbow trout fishing lasted slightly longer. Catches of tagged trout after 6 weeks were negligible. Only 10 trout were recovered during 1940 and 1 during 1941. Six of these fish were brown trout and 5 were rainbow trout. There was no evidence that any brook trout survived from one fishing season to the next.

Growth studies of trout planted in the fall indicated that rainbow trout grew fastest, followed by brown trout and brook trout. There was evidence that the growth rates of brown trout and rainbow trout decreased as the size of the fish increased. This was not true of brook trout.

Migrations of fall-planted trout were not extensive. Those undertaken averaged considerably less than 1 mile. Brown trout favored upstream and brook trout downstream movement, while rainbow trout moved in equal numbers in either direction. Spring-planted trout, captured after less than a month in the stream, had moved very little. A majority of brook trout and brown trout remained within the planting areas. About half of the rainbow trout migrated.

Fall planting of the three species of trout was nearly as efficient as spring planting, as 49 per cent of the former and 54 per cent of the latter were recovered. Eight per cent more brown trout from the fall plantings were recovered than from the spring planting. Recoveries of spring-planted brook trout and rainbow trout exceeded those of fall-planted trout by 8.8 per cent and 13.6 per cent respectively. Contrary to the common belief of anglers, fall-planted trout did not become "wild" over the winter. They were taken even more readily in the early fishing season than were trout of the spring plantings. The high returns from the fall plantings were attributed largely to the heavy fishing pressure, the moderate winter conditions, the lack of important predators, and to a possible scarcity of wild trout from natural spawning in Spring Creek.

Introduction

Anglers who visited the major trout streams of Pennsylvania during the few years preceding the declaration of war by Japan in December

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1941 are well aware of the heavy fishing pressure existing at that time. Today so many fishermen are either in the armed forces or have so little leisure time that the streams are enjoying a well-earned rest. It is to be reasonably expected, however, that in the years following the present conflict, there will be more anglers astream than ever before. This heavy fishing will perhaps call for new policies and procedures in the management of fishable waters.

Extensive plantings of hatchery trout are made to offset, at least in part, the annual kill which under present creel limits is exceedingly heavy. To provide good fishing in all trout streams of the state by plantings alone would probably be so expensive as to make fishing license fees prohibitive—a fact not usually appreciated by the average angler. However, the introduction of hatchery fish is very important in maintaining trout fishing at its present level in the heavily fished streams. This paper is concerned chiefly with the results obtained from trout plantings in a single Pennsylvania stream.

In order to evaluate the practical effects of trout plantings, it is necessary to make a check on the numbers of trout recovered by anglers. Experiments in other states indicate that this check is best made by marking or tagging trout before planting and by conducting a creel census on the stream. These methods were used in determining the behavior and ultimate fate of brook trout, brown trout, and rainbow trout planted in Spring Creek, Centre County, Pennsylvania. Since so much time and effort are expended in the rearing and planting of trout as well as in fishing for them, it is believed that the information presented in this paper will be of value to the fish-culturist and of interest to the angler.

Description of Spring Creek

Spring Creek is one of Pennsylvania's outstanding trout streams and among the most heavily fished. Although several tributaries rise in nearby mountains, the main stream flows for its major portion through agricultural lowlands.

The section selected for this study comprises about 3 miles of stream and is located about 1½ miles above the Pennsylvania Fish Commission's Spring Creek Project, known to anglers as "Fisherman's Paradise." The experimental section was located on the property of the Rockview Branch of the Western State Penitentiary. This location was chosen particularly because there were only two ways of approaching or leaving it. Consequently opportunity was afforded to interview nearly all anglers as they left the stream.

As the name suggests, Spring Creek is fed partly by springs. Large springs entering the stream at the upper limit of the experimental section, moderate the stream temperatures in this area to such a degree that suitable temperatures for trout are generally found throughout the year. In the upper half of the area the stream seldom freezes over while in the lower half, although freezes occur, they are neither severe

nor of long duration. The stream has an average width of about 35 feet in the experimental area and the mean volume of flow from October 1940 to September 1941 was estimated as 20,000 gallons per minute.

Bottom-fauna studies conducted over several years have shown Spring Creek to have a good food rating. Of special importance in the diet of trout during late May is the burrowing mayfly, *Ephemera guttulata*. This form appears in enormous "hatches" usually lasting about a week. During this period all three species of trout commonly forsake other foods and gorge themselves on this insect. Excellent catches of trout are made when these mayflies or imitations of them are used. Perhaps partially due to the influence of Fisherman's Paradise, where only artificial lures are allowed, much of the angling at the experimental area described here is with flies, particularly from the middle of May through the remainder of the open season.

Tagging Method

The method used in tagging was essentially that described by Shetter (1936). Clip-type tags bearing a serial number and lettered PENN were made secure around the left mandible of the trout by means of small pliers. Tags were always rounded to allow free movement around the jawbone. Observations were made of the effect of tagging on the mouths of the trout. Nearly all fish tagged in late fall had healed mouths when caught in April. Healing required from 3 to 5 weeks for those tagged in early April. About 3 per cent of trout tagged in the fall and caught in April had inflamed areas around the tag. Shetter (1937) found that there was no significant difference between the growth rate of tagged and untagged trout. Recently Schuck (1942) stated that over a period of 3 years tagged brown trout consistently weighed less than untagged fish when compared on a basis of mean standardized length. He further stated, however, that the correction factor found in this experiment could not be considered valid for other situations since such factors as size of trout and time in stream after tagging operate in determining the condition of tagged trout.

All tagging was done by the writer at either the Pleasant Gap Hatchery or the Spring Creek Project, both near Bellefonte. Standard and total lengths were taken in centimeters and later converted to inches.

Planting Methods and Numbers Planted

To facilitate migration studies, the spot-method of planting was used. The length of the planting section for the various lots of trout averaged about 100 feet. A trout was not considered to have migrated if it was recaptured anywhere within this 100-foot section. Since Spring Creek ordinarily receives both fall and spring plantings of brook trout, brown trout, and rainbow trout, all three species were planted for the experiment.

Table 1 gives all information on the plantings. Although all but one lot of trout planted in 1938 were released after winter had begun, all lots stocked in November and December will be referred to as planted in the fall. Approximately equal numbers of the three species were planted. The total number of spring-planted trout, however, was only about one-third that of the fall-planted trout.

The following information was recorded for each trout planted: (1) Species, (2) tag number, (3) length, (4) planting date, and (5) location of planting.

Following each planting the stream was visited several times. No dead trout were seen or reported.

Procedure in Creel Census

The project was well publicized in newspapers and signs with a description of the project, and instructions to anglers were posted along the stream. The open season for trout in Pennsylvania is from

TABLE 1.—*Summary of all plantings of tagged trout in Spring Creek*

Species of trout	Number planted	Average total length (inches)	Date
	Fall of 1938		
Brook	499	9.1	December 28
Brown	418	8.0	November 18
Brown	129	8.5	December 28
Rainbow	26	18.0	....
Rainbow	474	7.0	December 28
Total	1546	......	December 28
	Spring of 1939		
Brook	171	9.1	April 4
Brook	19	12.5	April 4
Brown	197	7.6	April 4
Rainbow	197	8.8	April 4
Total	584	......	....
Grand total	2130	......	....

April 15 to July 31 inclusive. The daily creel limit is 10 fish, and the minimum legal length is 6 inches. Fishing on the experimental area was permitted from 6:00 a.m. to 9:00 p.m. daily. Four checkers were employed during the first 3 weeks of the heaviest fishing. One man was stationed at each of the two exits while the other two worked up and down the stream. Every angler was approached at least once daily and his catch of tagged trout recorded. As an added precaution, the checkers at the exits checked catches as anglers left the stream. Following the first week in May, when fishing pressure had somewhat abated, only two checkers were used. Because of the small number of returns of tagged trout during June, no checkers were employed during July. Fishermen were relied upon to leave records of their catches on blank forms provided in boxes at the exits. Records of only four trout were turned in during July. About 15 voluntary returns came from fishermen who caught tagged trout above the experimental section, and 25 trout were reported from below the area. At Fishermen's

TABLE 2.—*Recoveries of tagged trout from Spring Creek 1939, showing migration trends*

Species of trout	Month recovered	Number of recoveries	No migration		Downstream migration			Upstream migration		
			Number	Percentage	Number	Percentage	Average distance (miles)	Number	Percentage	Average distance (miles)
Fall Planting										
Brook	April	226	109	48	85	38	0.85	32	14	0.71
	May	6	4	67	2	33	1.08	....	....	......
Brown	April	236	85	36	7	3	0.19	144	62	0.83
	May	56	26	46	....	....	......	30	54	0.80
	June	3	3	100	....	....	......	....	....	......
Rainbow	April	121	49	40	31	26	0.45	41	34	0.50
	May	98	44	45	29	30	0.49	25	25	0.35
	June	11	3	27	7	64	0.80	1	9	0.50
Spring Planting										
Brook	April	103	82	79	13	13	0.22	8	8	0.23
	May	3	1	33	2	67	0.15	....	....	......
Brown	April	45	34	76	1	2	0.25	10	22	0.47
	May	43	37	86	1	2	0.30	5	12	0.31
	June	4	4	100	....	....	......	....	....	......
Rainbow	April	70	33	47	25	36	0.23	12	17	0.54
	May	41	24	59	9	22	0.24	8	19	0.60
	June	5	2	40	2	40	0.10	1	20	0.55

Paradise, where all trout caught are weighed and measured, only three trout were recorded in 1939, none in 1940, and one in 1941.

On the opening day (1939) 960 anglers fished on the experimental section. This allowed about 33 feet of stream side per angler. This number was higher than normal probably due to the publicity given the project. A similar census in 1941 gave 736 anglers which allowed about 43 feet of stream side per angler on the opening day.

In fairness to the anglers visiting the project it should be stated that, with very few exceptions, they gladly permitted checkers to take the necessary data. Ninety-two per cent of all tagged trout recorded were examined by checkers; the remaining records were those of anglers.

Migration

The period of time between planting and the opening of the trout season was $3\frac{1}{2}$ months for trout planted in the fall, with the single exception of the one lot of brown trout planted in November, for which group the period was about 5 months. Only 11 days elapsed between the time of the spring planting and the opening of the season.

Table 2 presents data by lots from recoveries of 757 fall-planted trout and 314 spring-planted trout. Figures 1 and 2, based on data from Table 2, illustrate the percentages of migrants and non-migrants as well as the directions and average distances travelled by each species.

It will be seen (Fig. 1) that, of the fall-planted trout, 51 per cent of the brook trout, 61 per cent of the brown trout, and 58 per cent of the rainbow trout moved from the planting areas. For nearly all fish the distances travelled were considerably less than 1 mile. Differences were noted among the three species as to direction of migration. The nearest approach to movement in a single direction was found among brown trout, 59 per cent of which moved upstream as contrasted with only 2 per cent that moved downstream. Brook trout moved downstream more frequently than upstream, whereas rainbow trout showed no preference, moving in either direction in equal numbers. The average distances travelled by brook trout and brown trout were greatest in the direction toward which the greatest percentage moved.

Results from spring-planted trout (Fig. 2) were in part similar to those of fall-planted fish. Brown trout again favored upstream and brook trout downstream movement. Rainbow trout, however, had the greatest percentage of migrants and preferred downstream movement. Average distances travelled by brook trout and brown trout were generally less than for the fall-planted trout. However, the average distance travelled by spring-planted rainbow trout migrating upstream was somewhat greater than in the fall-planted rainbow trout.

Shetter (1937), working with tagged, wild brook trout in the North Branch of the Au Sable River, Michigan, found a scarcity of fish in winter and early-spring seine hauls. He concluded that the bulk of

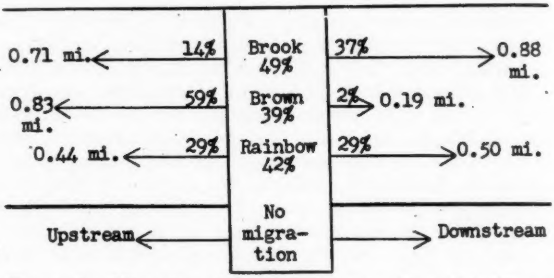

FIGURE 1.—Migration of 757 tagged trout. Planted in November and December 1938 and recovered in April, May, and June 1939.

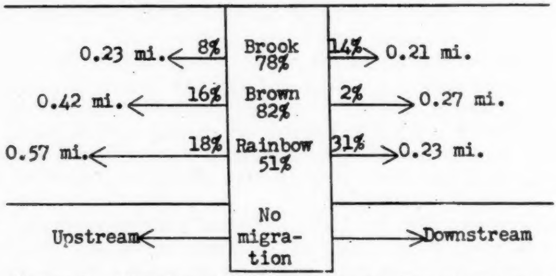

FIGURE 2.—Migration of 314 tagged trout. Planted on April 4, 1939 and recovered in April, May, and June 1939.

the trout population moved downstream during these months. The present studies show that no such extensive downstream migration in winter occurs in Spring Creek, at least insofar as recently stocked trout are concerned. Practically all of the fall-planted trout recovered were taken relatively near the planting areas. This lack of movement was possibly due to the moderate winter temperatures in Spring Creek.

Hazzard and Shetter (1939) demonstrated that in Pine River, Michigan, large-sized trout planted at any point distributed themselves rather uniformly throughout the surrounding area after 2 weeks, and when caught were taken relatively near (within 1 to 3 miles) the planting area. "Spot-planted" brook trout moved both upstream and downstream during the first 2 weeks following planting, with the majority moving upstream. Rainbow trout whether spot-planted or boat-planted (distributed relatively uniformly from a boat) showed a dominant upstream movement. A greater movement of trout followed spot planting than occurred when fish were distributed a few in each pool.

More recently (1941) Shetter and Hazzard, conducting studies on

several streams in Michigan, found that marked brook trout were usually caught within 5 miles of the point of release, but that the trend of the movement was downstream. Brown trout migrated less than brook trout. Rainbow trout undertook more extensive migrations and the general direction was downstream.

Hoover and Johnson (1938) planted tagged, hatchery brook trout in Bear Brook, New Hampshire, before the opening of the season. Eighty per cent of the recovered trout had migrated downstream and 20 per cent upstream during the first 20 days following planting—a condition somewhat paralleling the findings in Spring Creek. The writer believes that had a longer period of time elapsed between planting and recovery the behavior of the migrating individuals in Spring Creek might have changed considerably. The data are significant, however, since both planting and recovery periods are normal for Spring Creek.

Growth

Data on growth presented in Table 3 are based on recoveries of 567 fall-planted, tagged trout. Approximately 96 per cent of the measurements were made by experienced checkers; the remaining fish were measured by anglers. All measurements were scanned carefully and those obviously erroneous were discarded. The trout were placed in size groups according to species and the gain of each individual per day was calculated. The average increase per day was then determined for each size group. The method of reporting growth as the average increase per day in inches x 10 which was used by Shetter (1937), is used in the table. Excluding the last lot of rainbow trout (recovered in May), all recoveries were made during the period of April 15 to May 1, 1939.

Considerable differences were noted among the growth rates of the three species. In general, rainbow trout grew fastest and brook trout slowest while brown trout ranged between these two. The growth rate of brown trout and rainbow trout decreased as the size group increased. In the brook trout the opposite condition was true. The two lots of brown trout planted in November had a slower growth rate than did brown trout of the corresponding size groups planted in December. A comparison of the growth of the rainbow trout (size group 6-7.9 inches) recovered in April with the rainbow trout of the same size group recovered in May indicates an acceleration of the rate of growth as the season advances.

Shetter (1937) working with tagged, wild brook trout in the North Branch of the Au Sable River, Michigan, found the average growth rate (inches per day x 10) during early winter to be 0.02 for 6- to 8-inch fish and 0.03 for 8- to 10-inch fish. On the same basis the gain of brook trout in Spring Creek during winter and early spring was 0.043 and 0.050 respectively for the two classes. Watts, Trembley, and Harvey (1942) tagged wild brook trout from 4 to 8 inches long in several

TABLE 3.—*Growth of tagged trout planted in Spring Creek in the fall of 1938, and recovered during the early fishing season, 1939.*

Planted			Recovered April 15-30, 1939		
Species of trout	Date	Size group (inches)	Number of fish recovered	Average no. of days out	Average gain per 10 days (inches)
Brook	December 28	6-7.9	31	116	0.043
Do.	December 28	8-9.9	108	116	0.050
Do.	December 28	10-12.9	54	116	0.060
Brown	November 18	6-7.9	81	156	0.063
Do.	November 18	8-9.9	59	156	0.058
Do.	December 28	6-7.9	18	116	0.080
Do.	December 28	8-9.9	28	116	0.073
Rainbow	December 28	6-7.9	79	116	0.101
Do.	December 28	8-9.9	13	116	0.099
Do.	December 28	16-19.9	13	116	0.062
Do.[1]	December 28	6-7.9	83	139	0.126

[1]Recovered during May, 1939.

tributaries of Kettle Creek, Pennsylvania. Recoveries showed an annual growth of from 1 to 2 inches, dependent on the type of stream. Comparisons between the growth of these trout with those in Spring Creek are of doubtful value since growth periods for the latter are for winter and early spring only.

As far as is known there are no data on the growth of hatchery-reared trout planted in other Pennsylvania streams. However, because of the moderate winter temperatures and the amount of natural food present, the growth rates as shown in Table 3 perhaps represent the upper limits of winter and early-spring growth to be expected of stocked trout in Pennsylvania streams.

ANGLERS' RECOVERIES OF TAGGED TROUT

Numerous workers have reported on the recoveries of tagged or marked trout. Cobb (1933) planted 8,679 tagged brown trout and brook trout and obtained a recovery of 31 per cent in 10 Connecticut streams. Hoover and Johnson (1938) planted marked brook trout in New Hampshire streams in early June and obtained a 70 per cent recovery within 3 weeks. Shetter and Hazzard (1941) have conducted many tagging and marking experiments on Michigan streams. Over a period of three years the percentages of hatchery trout caught from various plantings were: Brook trout, 2.0 to 58.4; rainbow trout, 0.6 to 61.9; brown trout, 2.0 to 19.2.

Of the 2,130 tagged trout planted in Spring Creek a total of 1,081 (50.8 per cent) was reported captured. Table 4 presents information on these recoveries. Since the percentage caught on the first 2 days of the open season constituted a major part of the total percentage taken during the entire season, these days are listed separately. Other periods are of approximately 2 weeks each. The total percentages returned were surprisingly similar for the three species, as about half of the number of each species was recaptured (brook trout, 49.4 per cent; rainbow trout, 50.2 per cent; and brown trout, 52.6 per cent). This latter finding is at variance with those of other workers who have ob-

TABLE 4.—*Summary of anglers' recoveries during the 1939 trout season of tagged fish planted in Spring Creek in late 1938 and in the spring of 1939. The figures in parentheses show the percentages of the total recoveries from each planting made in the various periods.*

Item	Species of trout and date of planting: Brook Dec. 28, 1938	Brown Nov. 18, 1938	Brown Dec. 28, 1938	Rainbow Dec. 28, 1938	Rainbow[1] Dec. 28, 1938	Brook April 4, 1939	Brown April 4, 1939	Rainbow April 4, 1939	Total
Number of fish planted............	499	418	129	474	26	190	197	197	2130
Total recoveries	234	229	70	209	23	106	92	118	1081
Percentage of total recovered	47.0	54.8	54.3	44.2	88.6	55.8	46.7	60.0	50.8
Number recovered in period:									
April 15	188	60	33	40	13	70	14	18	436
	(80)	(26)	(47)	(19)	(56)	(66)	(15)	(15)	(40.4)
April 16	14	24	8	8	3	5	4	9	75
	(6)	(11)	(11)	(4)	(13)	(5)	(4)	(8)	(6.9)
April 17-30	20	81	18	55	2	18	26	45	265
	(9)	(35)	(26)	(26)	(9)	(17)	(28)	(38)	(24.5)
May 1-15	3	37	4	74	2	1	28	24	173
	(1)	(16)	(6)	(35)	(9)	(1)	(31)	(20)	(16.0)
May 16-31	3	11	3	21	2	2	17	17	76
	(1)	(5)	(4)	(10)	(9)	(2)	(19)	(14)	(7.0)
June 1-15	....	4	....	5	....	....	3	3	15
	....	(2)	....	(3)	....	....	(3)	(3)	(1.4)
June 16-30	....	....	....	4	....	....	....	2	6
	....	....	....	(2)	....	....	....	(2)	(0.6)
Date unknown	6	12	4	2	1	10	....	....	35
	(3)	(5)	(6)	(1)	(4)	(9)	....	....	(3.2)

[1]This lot of rainbow trout listed separately because of greater size (16 to 20 inches).

served that returns of brown trout are freqnently smaller than those of either of the other two species.

On the opening day slightly more than 40 per cent of the total number of tagged trout taken during the season were recovered. According to species, the percentages taken on the first day were: brook trout, 76 per cent; brown trout, 27 per cent; and rainbow trout, 20 per cent. This large initial kill of brook trout has been noted by other workers. It is well known by fishermen that brook trout are more easily taken in early spring fishing than are the other two species. By the end of the first 2 weeks 92 per cent of the season's total catch of the brook trout, 68 per cent of the brown trout, and 55 per cent of the rainbow trout had been taken. Thus, as far as tagged brook trout were concerned, catches were good for the first few days only, following which time they fell off rapidly and after 2 weeks were negligible. The plantings of brown trout provided fair fishing for about 1 month following the opening of the season after which time few were taken. Rainbow trout provided better fishing than did either the brook trout or brown trout following the first 2 weeks. However, even with this species, fishing might have been termed poor after 6 weeks. It is thus evident that plantings such as those made here can not be expected to maintain good fishing in Spring Creek throughout the entire season.

Fall and Spring Planting

Numerous experiments have been designed to test the relative efficiency of fall and spring plantings of trout. Cobb (1933), Nesbit and Kitson (1937), and Shetter and Hazzard (1941) all have demonstrated that the percentages of fall-planted trout recovered are quite generally very low in comparison with recoveries of spring-planted trout. Shetter and Hazzard (1941) found that recoveries from fall-planted trout in Michigan streams did not exceed 5.3 per cent, while spring and open-season plantings resulted in recoveries by anglers of from 4.9 to 61.9 per cent of the fish released. Similarly, Smith (1941) found that in a northern Michigan stream, where the fishing intensity was relatively light, a maximum of only 1 per cent of fall plantings of brook trout was taken by anglers, whereas a maximum of 19.6 per cent of spring-planted fish was recovered.

As shown in Table 5, there was no significant difference between the recoveries of fall-planted and spring-planted trout, for 49.4 per cent of the former and 54.1 per cent of the latter were caught by anglers. Judging from these figures, spring planting was only 5 per cent more efficient than fall planting. It should be noted that the total number of trout planted in the spring was only one-third that of the number planted in the fall. Shetter and Hazzard (1941) found that smaller plantings of trout (100 to 160 trout per mile of stream averaging 50 feet wide) resulted in relatively higher returns to the angler than did larger plantings. If this condition exists in Spring Creek, the returns

from fall plantings are even more significant. The returns from fall plantings of brown trout were higher by 8 per cent than were the returns from the spring planting. The percentages of brook trout and rainbow trout recovered from spring plantings exceeded those from fall plantings by 8.8 and 13.6 per cent respectively.

Many Pennsylvania anglers favor fall plantings in the belief that hatchery trout become "wild" over the winter and are thus caught out less readily. The behavior of hatchery trout in Spring Creek, however, does not support this view. Table 4 indicates that greater percentages of trout (three species) were caught during the first 2 days of the season from fall plantings than from spring plantings.

Hazzard (1941) suggested that the small returns obtained from fall plantings of trout in many northern streams are due to severe winter losses. He attributed these losses to such factors as: increased exposure in the fall before ice forms and in the spring after the ice leaves; predators such as American Mergansers; the effects of floods and "anchor ice" upon shelters and food of trout; and a restricted trout diet during winter. Undoubtedly these factors are of much importance in most northern streams.

TABLE 5.—*Comparison of recoveries from fall and spring plantings of tagged trout in Spring Creek, 1939.*

Species of trout	Planted		Recovered	
	Date	Number	Number	Percentage
	Fall planting			
Brook	Dec. 28, 1938	499	234	47.0
Brown	Nov. 18, 1938	418	229	54.8
Do.	Dec. 28, 1938	129	70	54.3
Rainbow	Dec. 28, 1938	500	232	46.4
Total	....	1,546	765	49.4
	Spring planting			
Brook	April 4, 1939	190	106	55.8
Brown	April 4, 1939	197	92	46.7
Rainbow	April 4, 1939	197	118	60.0
Total	....	584	316	54.1

As stated in the description of Spring Creek, the several springs entering the stream at the upper end of the experimental area moderate somewhat the winter temperatures. As a result, the stream in this area freezes over only infrequently and usually for only short periods of time. Some anchor ice does form, however. Since the drainage area is not extensive, floods are not common although there is usually a spring freshet. In 1939 the highest water came during March, before the spring planting was made. No thorough study of the predators of trout in winter on this area was made but there have been no records of American Mergansers there. Furthermore, bottom-fauna samples taken during winter have shown Spring Creek to have a good supply of trout food. During one of the coldest days of January 1939 the writer observed trout rising for insects.

From the above discussion it appears that the high returns of fall-

planted trout in Spring Creek may be due to the biological and physical characteristics of the stream itself. Other factors, however, may have operated also. Shetter and Hazzard (1941) believed that a large population of wild trout from natural spawning in Michigan streams may lessen the chance of survival of trout introduced from hatcheries particularly for fall plantings. The numbers of wild trout in Spring Creek are not known but, because of the heavy fishing pressure which has existed there for years, it is possible that a scarcity of wild fish does exist. Perhaps this condition, if present, might have been a factor favorable for the survival of trout released in the fall.

Much further work is needed in Pennsylvania before these questions can be answered. It seems logical to assume, however, that in Spring Creek and possibly in similar spring-fed streams, the fish-culturist can plant trout in the fall with reasonable expectation of a fairly high survival. This fact is of importance since fall plantings lighten the burden of the spring distribution of trout and reduce the cost of food appreciably.

Low Survival of Tagged Trout from One Fishing Season to the Next

The failure of marked trout planted in streams to survive from one fishing season to the next has been noted by several workers. Shetter and Hazzard (1941) stated that, "The marked fish surviving from one season to the next constituted an insignificant percentage of the total catch." They found that spring-planted trout more often survived to the second season than did fall-planted trout, and that the greatest numbers of trout recovered after two winters came from summer-planted fish.

At the close of the 1939 fishing season, 1,081 tagged trout had been recovered by anglers. This removal left a theoretical reserve of 1,049 trout. Undoubtedly the actual number was somewhat less since some catches were probably missed by the checkers and since some of the trout migrated beyond the limits of the experimental area where checkers did not commonly operate. During the first 2 weeks of the 1940 fishing season, two checkers covered the experimental area. Only 10 tagged trout were recovered of which 6 were brown trout and 4 were rainbow trout. Of the six brown trout, one was planted in the fall and five were planted in the spring. Three of the four rainbow trout recovered were planted in the fall and one was planted in the spring. No checkers were on the stream during the next fishing season (1941). However, one return was made. This return was from a rainbow trout, planted in the spring, which had migrated downstream about 2 miles to Fisherman's Paradise where it was captured and measurements taken. According to these very limited data, it appears that chances of survival are best in brown trout and next best in rainbow trout. There was no evidence that any brook trout survived from one season to the next. Since the theoretical reserve left at the

end of the first fishing season included only about one third as many spring-planted as fall-planted trout and since 7 of the 11 trout taken during the 1940 and 1941 seasons were spring-planted, it will be seen that the chances of survival among spring-planted trout are several times higher than those of fall-planted trout.

Significance of Findings and Need for Further Investigations

These findings are based on data from only one stream and the results obtained are applicable therefore only to Spring Creek and possibly similar streams. The original plan of the writer was to conduct work of this nature on several types of streams but, due to the war emergency, this work has been discontinued temporarily. It is hoped that these studies will serve as a basis for future investigations in other Pennsylvania waters.

Inasmuch as this experiment was the first of its kind in Pennsylvania, the writer felt it best to keep the number of questions asked the fishermen to a minimum. For this reason neither the numbers of untagged trout entering the catch nor the man-hours fished were recorded. Information on both of these points is of course important in the final analysis of the effectiveness of plantings of hatchery trout.

The most surprising result of the study was the relatively high return of hatchery trout planted in the fall as compared with the return of similar plantings in other states. The fact that fall plantings are only 5 per cent less efficient than spring plantings may be an argument for heavier fall plantings.

It is apparent that the number of trout planted in this experiment can not be expected to provide good fishing for more than a month of the early open season. In view of the heavy, pre-war fishing pressure, it would seem logical to assume that fishing can be maintained at a high level only through heavier stocking or a reduction in the creel limit.

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THE INTRODUCED FISHES OF NEVADA, WITH A HISTORY OF THEIR INTRODUCTION

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ABSTRACT

At least 39 species and subspecies of fishes have been introduced into the waters of Nevada since 1873. Of these, 24 kinds are now known to occur in the state. A thorough survey of the exotic fishes has not been made, but specimens or records of introduced species have been kept in the course of rather extensive collecting of the native fish fauna from 1934 to 1943. Consequently it is believed that the number of introduced species herein enumerated approaches a complete tabulation. Some additions among the sunfishes and catfishes may be expected.

The annotated list is divided into two parts: species now present in the state, and species introduced but never established. The established kinds constitute about two-thirds of the total number of known native species, but are far outnumbered by the indigenous fishes when all the local subspecies (Hubbs and Miller, in press) are included.

The stocking of cutthroat trout and rainbow trout in the same creek should be discouraged since these two species hybridize extensively and the cutthroat trout are speedily eliminated. Brook trout and cutthroat trout, however, do not hybridize. A suggested practice would be to select separate streams when planting rainbow and cutthroat species, a procedure greatly simplified by the presence of many isolated creeks throughout the state.

The further distribution of the green sunfish, *Lepomis cyanellus*, is not recommended as this species is a serious competitor and does not reach a size suitable for game fishing.

INTRODUCTION

Since 1872, the year after the U. S. Fish Commission was established, fishes native to parts of this and foreign countries have been widely introduced into waters of the American West. The history of early plantings in Nevada is meager but, according to published reports and local testimony, some of the first successful introductions took place between 1873 and 1877 when cutthroat trout were planted in central and eastern Nevada, and catfish and Sacramento perch were stocked in Washoe Lake. In succeeding years attempts have been made to establish at least 31 species (39 kinds) in public or private waters and 24 of these varieties are now known to occur in the state. These figures include three species (four forms) which are, or were, native to Nevada.

Most of the information relating to the history of introductions

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which we present was obtained from the Reports, Bulletins, and Statistical Digests of the U. S. Fish Commission, later the U. S. Bureau of Fisheries and now the U. S. Fish and Wildlife Service, and reports of the Fish Commissioner of the State of Nevada covering the years 1877 to 1894, inclusive, the Nevada Fish Commission (1895-1896 and and 1907-1916), and the Nevada Fish and Game Commission (1917-1942). Reports for the period 1897 to 1906, inclusive, could not be found and the authors understand that the Nevada State Fish Commission did not exist during these years.

The annotated list is divided into two parts: First, those species known to occur in the state at the present time, and second, species which according to reports have been introduced, but have never become established. The distribution given for many of the species is not to be considered complete since no extensive survey of the introduced fishes of the state has yet been made. The history of introductions will probably never be completely known because transplants made by private individuals and by the counties generally have not been recorded. In Nevada the county commissioners carry on much of the local administration. Some of the state records give only the total number of fish planted, making no mention of the genera or species involved. Other reports list the fish under the names of bass, bream, and sunfish, which do not admit of specific identification.

Jordan and Evermann (1898: 2818-2819) have been followed in the classification of cutthroat trouts, a practice adhered to by most ichthyologists. The common name Lahontan cutthroat trout (*Salmo clarkii henshawi*) is used in preference to that of Tahoe cutthroat trout, since this subspecies has been found throughout the streams draining into the basin of Pluvial Lake Lahontan. Eddy and Surber (1943: 89) used this name (though misspelling it Lahonton). In the general classification Hubbs and Lagler (1941) have been followed.

The authors are grateful to various officials of the Navada Fish and Game Commission for helpful information. Dr. Carl L. Hubbs has made valuable suggestions and has permitted the publication of his field observations. Mr. William A. Dill of the California Division of Fish and Game has read the manuscript and offered critical data on the history of introductions. Full cooperation has been received from the Division of Fish Culture of the U. S. Fish and Wildlife Service and from the U. S. Forest Service.

I. Introduced Species Now Known to Occur in Nevada

Salmonidae (Trouts)

1. *Salmo trutta fario* Linnaeus. Brown trout. This species occurred in the Truckee River about 1906 (Anonymous, 1907: 44) and was again recorded from that river in 1911-1912 by Snyder (1917: 85). *Salmo trutta* has been planted extensively in the Tahoe area, and Mr. Dill writes that the first plant of this species which could have entered

Nevada took place in July 1895, when 250 Loch Leven trout, about 3 inches long, were deposited by the California Commission in Webber Lake, Sierra County, California (Smith, 1896: 433). The outlet of this lake is the Little Truckee River, a tributary of the Truckee River. During 1929-1930, 150,000 eggs and fish were received by applicants in Nevada (Leach, 1931: 1181). In 1930 a total of 50,000 "Loch Leven trout" were planted in Smith Creek, Big Creek and Birch Creek, all located in southern Lander County (Anonymous, 1931: 37). Shipments of eggs and fish were again made in 1932-1933 and 1935-1936. In 1941, 210,000 "Lockleven trout" were planted in Churchill (40,-000), Douglas (61,000), Nye (55,000), and Washoe (54,000) counties (Anonymous, 1942: 14-15).

The brown trout is now known from the Reese, Carson, Truckee, and Walker Rivers and numerous mountain streams. Owing to the hatchery practice of mixing the strains of brown and Loch Leven trout (*Salmo trutta levenensis*), we are unable to distinguish the two subspecies and refer them both to the above form. It is very doubtful that a pure strain of the Loch Leven variety has been maintained anywhere in the United States.

2. *Salmo clarkii henshawi* Gill and Jordan. Lahontan cutthroat trout. Although this subspecies is native to the hydrographic basin of Pluvial Lake Lahontan, it has been widely introduced into streams, rivers, and lakes throughout the state. It has also been distributed to other western and eastern states.

The history of early plantings is known in detail only for Big Smoky Valley, in Nye and Lander counties. The following account is taken directly from the field notes recorded by Dr. C. L. Hubbs on August 9, 1938, when he interviewed pioneer resident George Schmidtlein on his ranch in Big Smoky Valley.

In August, 1873, George and his brother Henry, with a neighbor named Smiley, hired an Indian and his wife with a pack train to stock Kingston Creek with trout from the Reese River system. The native trout occurred in Reese River and ran into Big Creek, Washington Canyon, San Juan Creek, and other tributaries on the western slope of the Toiyabe Range. They turned the little stream and caught 139 fish, none over 6 inches long, and put them in syrup and vinegar kegs. Those in the syrup kegs died but those in the vinegar kegs "thrived." The fish were packed across three summits for four days with changes of water and retention of the fish overnight in small, dammed ponds. Finally 39 fish were brought through and put in a dammed pond where they were fed for a week. The planting was successful, for despite some dynamiting two years later and turning of the creek rather regularly, the trout multiplied rapidly, and there was good fishing in three years. From Kingston Creek the trout were soon planted in nearby streams on the eastern side of the Toiyabes (Birch Creek, Clear Creek, Ophir Creek, Twin Rivers, etc.), and also into Peavine Creek at the southern end of the range. Further plants were made in Grass

Valley, northeast of Austin, in one stream on the east side of Big Smoky Valley (in the Toquina Mountains), in Stoneberger Creek over the mountains, and in Roberts Creek near Eureka.

In the season of 1910 a total of "1,500,000 spawn of the Black spotted trout" was taken by the Nevada Fish Commission from the Truckee River (Anonymous, 1911b: 7). Between 1920 and 1927, over 390,000 blackspotted trout (presumably *S. c. henshawi*) were stocked in the waters of the Nevada National Forest and some adjoining streams (data furnished through the courtesy of G. W. Southwick, Acting Forest Supervisor of the Nevada National Forest). Collections continued almost annually until 1929 when "operations for the collection of blackspotted trout eggs at the Pyramid Lake field station resulted in a take of some 3,000,000 eggs within a period of 12 days during 1929" (Anonymous, 1931: 25). To our knowledge, no eggs of this subspecies were taken after 1930 from the Truckee River or Pyramid Lake.

The distribution of this fish and of the Yellowstone cutthroat trout, *S. c. lewisi*, by the Nevada Fish and Game Commission was made under the heading of "blackspotted trout." Information available indicates that, for the most part, the largest proportion of such trout distributed were of the *henshawi* variety.

Almost every county in the state has, at some time prior to 1930, received large numbers of this fish. In 1910 the Nevada Fish Commission distributed 1,347,151 "blackspotted trout" in Nevada. These fish went to Elko, Humboldt, Washoe, Lander and White Pine counties.

The existence in Nevada today of pure strains of the Lahontan cutthroat trout is uncommon or rare because of the hybridization between *Salmo clarkii lewisi* and *Salmo clarkii henshawi* and the artificial and natural crossing of cutthroat and rainbow trout. For this reason it is extremely difficult to identify with certainty the subspecies of *Salmo clarkii* now present in Nevada.

3. *Salmo clarkii lewisi* (Girard). Yellowstone cutthroat trout. This is the "blackspotted trout" of fish culturists which has been widely introduced throughout the West. During the fiscal year 1918, 50,000 eggs of this subspecies were sent to the Nevada Fish and Game Commission at Ely (O'Malley, 1919: 9, 29). We have found no record of the hatching and distribution of these fish but assume they were hatched at the Ely hatchery for distribution in White Pine County. The fish hatched from the 150,000 eggs received by Nevada from Yellowstone Park, Wyoming, during 1925 were distributed along with the Lahontan cutthroat trout into Mineral (Walker Lake), Elko, Washoe and Lander counties (Anonymous, 1927: 18-21). In the same year applicants in Nevada received 8,400 fish and eggs (Leach, 1927: 376). Between 1930 and 1937, 2,023,500 fish and eggs were sent from federal hatcheries to the Nevada Fish and Game Commission and to applicants in Nevada. Biennial reports of the Nevada Fish and Game Commission make no

mention of blackspotted or cutthroat trout for the fiscal years 1931-1942, inclusive.

During the fiscal years 1940 and 1941 and the calendar year 1941, 308,740 "fry, fingerlings, etc.", were introduced into waters of the Humboldt National Forest, and in 1941, 13,000 "fry, fingerlings, etc.", were shipped to the Nevada National Forest. In the calendar year 1941, 50,000 were sent to the Toiyabe National Forest, and over the same period, 652,840 eggs and fish were received by the State Commission and by applicants (Leach, James, and Douglass, 1941: 563, 569, 603; 1942: 6, 10, 24; and 1943: 6, 11, 25).

No information has been obtained concerning the disposition of the fish reportedly sent to the Humboldt National Forest, but G. W. Southwick writes that plants of "native" trout were made in a number of creeks of the Nevada National Forest in 1941. Further, Mr. Jay L. Sevy, Acting Forest Supervisor of the Toiyabe National Forest, wrote that cutthroat trout have not been planted in waters of this forest (main divisions in central Nevada) over the period 1936 through 1942. In the northern or Santa Rosa Division of this forest, in Humboldt County, cutthroat trout were formerly present. However, as they did not do well there, later plantings have all consisted of rainbow trout, the only salmonid now present (data kindly supplied by S. R. Justice, District Forest Ranger). Additional introductions were made into Walker Lake in 1941 and 1942 (statement of County Clerk Buckingham of Mineral County).

The hatchery source for Yellowstone cutthroat trout is the Springville Hatchery near Utah Lake, Utah, which receives its stock from Yellowstone Park.

4. *Salmo clarkii utah* Suckley. Utah Lake cutthroat trout. This subspecies, native to the basin of Pluvial Lake Bonneville in Utah and adjoining areas, was introduced prior to 1881 into Cleve Creek, Spring Valley, White Pine County, by pioneer settlers, and it subsequently has been distributed to many of the tributaries of that valley (statement given to Carl L. Hubbs on August 22, 1938, by "old-timer" John Yelland of Ely, Nevada). The fish are supposed to have come either directly or indirectly from Trout Creek, Juab County, Utah.

According to testimony given to Dr. Hubbs, on July 26, 1942, by Mr. Moorman and ranch hands at Moorman Ranch (= Illipah), Jakes Valley, 33 miles by U. S. Highway 50 west of Ely, "speckled trout" were stocked near the ranch in 1876. Illipah Creek, the only live stream entering Jakes Valley, rises in a large, permanent mountain spring in the White Pine Mountains, known as Waterworks Spring, because of its use many years ago as the water supply for the great Hamilton mining district. In 1876 large tanks then in use on the top of the mountain were stocked with the trout by mine owners. Later, when the water system was abandoned, the trout were turned loose into Illipah Creek as the initial plant. Several other kinds of introduced trout recently have been introduced into the stream, and prob-

ably none of the original strain is left. It is not known from where the first fish were obtained, but there is a good possibility that they too came originally from Trout Creek, Utah. On the other hand, they may have been Lahontan cutthroat trout, brought in from the stock in Big Smoky Valley or from the South Fork of the Humboldt River to the north.

A pure strain of this subspecies may no longer exist in Spring Valley or along the eastern border of Nevada because of subsequent plantings of rainbow trout and cutthroat trout (presumably *S. clarkii lewisi* and *S. clarkii henshawi*), according to data submitted by G. W. Southwick.

5. *Salmo gairdnerii irideus* Gibbons. Coast rainbow trout. This subspecies of rainbow trout has now become widely established. The Shasta rainbow trout (or McCloud River trout) of fish culture, *Salmo gairdnerii shasta* (also recorded as *Salmo stonei* and *Salmo gairdnerii stonei*) was the form stocked for many years from McCloud River, California. Early in fish-cultural work, however, the purity of this subspecies was affected by admixture with other forms, principally from the Klamath River, and later from the Rogue River, Oregon (Coker, 1920: 6-7). The tendency to mix hatchery stocks is well known, as pointed out by Smith and Needham (1942: 24). It is probably impossible to determine when *irideus*, rather than *shasta*, began to be utilized for stocking, but all of the rainbow trout from Nevada which we have collected (since 1938) are referable to *irideus*.

In 1879-1880, 2,500 eggs of the "M'Cloud River Trout," furnished by the U. S. Fish Commission, were successfully hatched and placed in tributaries of the Carson River (Parker, 1881:4). This record appears to be the earliest of the rainbow trout in Nevada. Parker (1883: 9) said that he hatched this trout in western Nevada in 1881-1882 for distribution into waters of the State. In 1893-1894, the U. S. Fish Commission shipped 40,000 rainbow trout eggs to the Nevada Fish Commission (Anonymous, 1896: 67, 79). During the next 3 years a total of 141,614 eggs were shipped by the U. S. Fish Commission.

In May 1895, 75,000 rainbow trout eggs were shipped from the Berwick Fish Commission Station of California to Nevada, and another shipment of 125,000 eyed ova was received by the Nevada Fish Commission from the Berwick Station on March 6, 1896 (Mills, 1897: 5, 12). About this time, the Shasta rainbow trout had evidently become established in the Truckee River as Jordan and Evermann (1896: 502) remarked that this subspecies (listed by them as *Salmo irideus shasta*) had been introduced into that river.

In 1904-1905, 2,500 fingerlings, yearlings, and adults were planted in the Humboldt River at Elko (Anonymous, 1906: 19). According to Sumner (1940: 220), rainbow trout were introduced into the Truckee River in 1907 or 1908. However, the Truckee River was used for the taking of spawn for the greater portion of "rainbow trout" distributed in the year 1907 by the Nevada Fish Commission (Anonymous, 1909: 5). Since 1908, shipments of rainbow trout have been

made to Nevada each year, by the Federal Government. The total number of eggs and fish allotted to Nevada amounted to more than 11,000,000 during the period 1908-1941. A complete list of localities where rainbow eggs were procured is not available, but since 1920 the Nevada Fish and Game Commission has obtained additional rainbow trout eggs from: The Nevada Consolidated Copper Corporation, Ely, Nevada; U. S. Bureau of Fisheries, Springville, Utah; Meader Trout Farm, Pocatello, Idaho; F. V. Klinke, Fortine, Montana; Crystal Lakes Fish Hatcheries (no address given); Cape Cod Trout Company, Wareham, Massachusetts; Wild Rose, Wisconsin; Saratoga, Wyoming; Cedar Island Lodge, Brule, Wisconsin (Anonymous, 1921: 9; 1923: 11; 1927: 14; and 1938: 6).

This species is now widespread in mountain streams and rivers, in many of which it has brought about the disappearance of the native cutthroat trout (*Salmo clarkii henshawi*), as well as of other subspecies, through extensive hybridization. Snyder (1917: 85) indicated that the native trout gave way to rainbow trout in the rivers and lakes. Moreover, the two species have been artificially crossed and the hybrids liberated in various streams. Rainbow trout are known also from several lowland springs in the state.

6. *Salmo gairdnerii irideus* × *Salmo clarkii henshawi*. Hybrid trout. Prior to 1911 the Nevada Fish Commission experimented "for some five years with Hybrid trout, a cross between the Lake trout (*Salmo mykiss henshawi*) and the Rainbow trout (*S. iridius*)" (Anonymous, 1911b: 13). Between June 7 and August 15, 1910, 131,785 fry of this hybrid combination were planted (Anonymous, 1911b: 44-45) as follows:

Clear Creek, Ormsby Co.	3,000;
Stoney Lake, Ormsby Co.	5,000;
Truckee River, Washoe Co.	123,785.

In 1913 hybrids were planted in the Humboldt River near Elko and Golcondoa and in the Truckee River. An additional lot of 14,000 eggs was shipped to the fish hatchery near Ely in White Pine County, for distribution in that area (Anonymous, 1915: 28-30). No mention is made of hybrids from 1914 to 1919 inclusive but in 1920, hybrids of rainbow trout and blackspotted trout were distributed in the Humboldt River near Carlin and Elburz in Elko County (Anonymous, 1921: 17).

7. *Salvelinus fontinalis fontinalis* (Mitchill). Common or eastern brook trout. The circumstances of the early introduction of this species into Nevada seem to be obscure. Eastern brook trout were planted in Prosser Creek, in Nevada County, California, in 1875 (Smith, 1896: 434). Since this stream is a tributary of the Truckee River, some of these fish or their progeny could have entered Nevada. Smith stated further that brook trout had become acclimated in Marlette Lake, on the northeastern side of Lake Tahoe, by 1892; apparently the first plant in Nevada took place about 1880. Mills (1891: 4) re-

ported the seining of eastern or "red spotted" trout from Marlette Lake in the fall of 1889 and in 1890 for the purpose of obtaining eggs for the hatchery located at Carson City. In 1883, fry were planted in the Carson, Walker, Truckee, and Humboldt rivers and in Washoe Lake, with very good results. Large plants were again made in these streams (except Walker River) and in Lake Tahoe in 1891, 1892, and 1893. Since the turn of the century the species has been widely stocked. A total of 3,474,345 eggs and fish was received by Nevada from federal hatcheries between 1901 and 1941. In addition to these, many eggs have been purchased from other hatcheries and additional millions of eggs have been obtained from fish seined in Marlette Lake.

This species is now one of the most common and widespread of the trouts in Nevada and is especially common in the higher mountain streams.

8. *Cristivomer namaycush namaycush* (Walbaum). Common Lake trout or Mackinaw trout. In 1885, 100,000 eggs of this species were sent to the Nevada Fish Commissioner and apparently about three-fourths of these arrived in good condition (Smith, 1896: 433). It is probable that some of these were planted, but no accurate account of their fate is available. The first definitely recorded plant was made in 1889, in and around Lake Tahoe, and a later plant was made there in 1895 (Smith, *loc. cit.*). Mills (1897: 22) wrote that on May 28, 1896, 48,000 Mackinaw trout were planted in Lake Tahoe, Douglas County. This fish is now very abundant in Lake Tahoe (Curtis, 1942: 6) where it is accused of having greatly reduced or virtually eliminated the Lahontan cutthroat trout, *Salmo clarkii henshawi*, and the royal silver trout, *Salmo regalis*, particularly the latter species. In 1907-1908, 27,245 fry of this species were introduced into Walker Lake, Truckee River, and Lake Tahoe (Anonymous, 1909: 18-19).

CYPRINIDAE (MINNOWS)

9. *Cyprinus carpio* Linnaeus. Carp. The first definite record of the introduction of carp into Nevada is for 1881, when fish were distributed to two counties in the state (McDonald, 1884: 1126). Between 1882 and 1891, 2,763 fish were planted. Cary (1887: 8) said that carp were distributed to persons in Washoe, Eureka, Churchill, Lyon, Douglas, Lander, Ormsby, Humboldt and Elko counties in 1885 and 1886. After 1891 the introduction of this species was apparently terminated. As is well known, however, the damage had already been done. There is the possibility that carp were introduced as early as 1873 (or between 1873 and 1878) from California, since Poppe (1880: 665) stated that young of the carp established in California in 1872 were "sold to farmers throughout California and adjacent States. . ."

Many of the introductions made between 1882 and 1891 were very successful. In an early report Mills (1891: 5) stated, "Several years ago the U. S. Fish Commissioner very generously allotted carp to this

state. Both of my predecessors made the distribution as directed by the Commission. . . . I am informed that in several private ponds and reservoirs they have multiplied so rapidly that they have come to stay. . . . Another carp grower, Mr. Thomas Oliver, of Carson City, Ormsby County, was the recipient of one of these shipments. At his ponds, one mile south of Carson City, they multiplied so rapidly and grew so fast that he not only supplied his friends, but generously drew on his ponds for young carp to fill orders addressed to the Nevada Fish Commissioner, Mr. Parker. Mr. Oliver had made arrangements to enlarge his ponds when the earthquake of June 3, 1887, wound up business by leaving him without water or carp."

The high esteem in which carp were held in the early days is attested by the words of Pasco (1882) who wrote to the U. S. Fish Commissioner urging that carp be stocked in the streams around Belmont, Nye County, and who used his influence in restraining neighbors from planting cutthroat trout from Reese River. "When I tell you that last winter trout [presumably *Salmo clarkii henshawi*] came from Truckee and Walker Rivers embalmed in snow and ice, and sold for 37½ cents per pound, you will see that we have reason to be anxious about the matter. The big thing is to get a good start (to get the fish), get them to breeding and we will supply and stock the country. I would give $5 for a pair that are big enough to spawn now. . . Last season I persuaded the man above me on my stream not to go to Reese River after trout, because I hoped sooner or later to get carp, and I did not want trout in the stream to eat the young."

This species is now very abundant in lower river courses, warm lakes (including Lake Mead), sloughs, and isolated springs throughout the state. It ascends the Humboldt River at least as far as Deeth, Elko County. Hall (1925: 158) and Bond (1940: 247) recorded carp as a food item of the white pelican in Pyramid Lake. Alcorn (1943: 35-36) found them in the stomachs of these birds in the vicinity of Fallon, Churchill County. This species was observed in excessive numbers in the Carson River between Dayton and the Lahontan Reservoir, and in the Walker River between Wellington and Walker Lake, in the latter part of August 1942. The "mirror" (partly scaled) and "leather" (few or no scales) varieties are not uncommon.

10. *Carassius auratus* (Linnaeus). Goldfish. Apparently there are no early records of the introduction of this fish into Nevada, although it is known that goldfish were introduced into the West before the turn of the century (1884 or earlier). Its widespread use as an ornamental aquarium fish suggests a means by which this species may have entered the waters of Nevada. Rather than kill their pets, owners have probably dumped them into the nearest water on many occasions; others have deliberately introduced them into ponds and springs. The utilization of this species as live bait may also account for its distribution in Nevada. In 1917 goldfish were planted in a reservoir near Las Vegas (Anonymous, 1919: 13).

This species has been taken in Big Shipley Spring, on the west side of Diamond Valley, Eureka County; in the upper spring ditch on Dairy Ranch just below McGill, White Pine County; and in the spring and outlet on Campbell Ranch, about 18 miles north of Ely, White Pine County—all in August 1938. Goldfish were present in 1939 in a spring-fed reservoir on Steve Collins' ranch in Ash Meadows, southern Nye County. This species was also noted by Hubbs in a small reservoir fed by a hot spring, 1.3 miles south of Cherry Creek (old town), in northern White Pine County. Goldfish are to be expected at other scattered localities throughout the state.

11. *Gila atraria* (Girard). Utah chub. This minnow was introduced by Mormon settlers into springs at Shoshone, Spring Valley, White Pine County, and on the Geyser Ranch in Duck (or Lake) Valley, northern Lincoln County, according to the testimony of John Yelland, old-timer at Ely. The same species occurs in springs on Murphy Ranch, along the western side of Steptoe Valley, White Pine County, almost surely as the result of another introduction (Hubbs and Miller, in press). The Utah chub is native to Nevada within the hydrographic basin of Pluvial Lake Bonneville, along the extreme eastern border of the state.

AMEIURIDAE (CATFISHES)

12. *Ictalurus lacustris punctatus* (Rafinesque). Southern channel catfish. Information on the early introduction of the channel catfish into the West is vague. In Nevada, this species is known only from the Colorado River drainage. It occurs in Lake Mead and below Boulder Dam (Moffett, 1942: 82; and 1943: 182) and also in Moapa (Muddy) River and probably in the lower Virgin River, both northern tributaries of Lake Mead. The earliest date of introduction into the Colorado River appears to be 1892-1893, when 722 adults and yearlings were received by the Arizona Fish Commission (Worth, 1895: 127). We have been unable to determine what happened to these fish. According to Game Warden Frank Wait of Las Vegas, this species was first introduced into the lower Colorado River about 1906 (personal interview). Channel catfish are now common in the lower Colorado River.

13. *Ictalurus catus* (Linnaeus). White catfish. This species may possibly have been introduced into Nevada with *Ameiurus nebulosus* in 1877. If it was, it did not become established.

About 1938 Mr. William A. Powell, Jr., Secretary of the Nevada Fish and Game Commission, caught on hook and line 39 large white catfish from Clear Lake (near Kelseyville), Lake County, California, and transplanted them to the vicinity of Fallon (personal interview). In 1939, 500 "blue catfish" were transferred from the California State Central Valleys Hatchery to the State of Nevada (Anonymous, 1941b: 88-89). Mr. Dill informs us that these fish were *Ictalurus catus*. According to Mr. Powell, he obtained 500 "rescued" fish of

this species from the Elk Grove Hatchery, California, in 1939, and planted them in the vicinity of Fallon, both above and below the Lahontan Dam.

We have seen only two specimens of this catfish from Nevada. One was taken 6 miles north of Stillwater, Churchill County, on April 5, 1943, by J. R. Alcorn and V. L. Mills; the other specimen was collected by Alcorn in a drainage ditch 1 mile north of Stillwater, on August 15, 1941. Both were caught on hook and line. Vernon L. Mills, State Game Warden, reports that fishermen, as well as himself, have taken a number of the small white catfish.

Since this species is particularly adapted to large rivers, any further plants in Nevada should be made in large reservoirs. This species is called the "fork-tail catfish" in California.

14. *Ameiurus melas catulus* (Girard). Southern black bullhead. Two young of this subspecies were taken in Las Vegas Creek at Las Vegas, Clark County, on August 30, 1938. No information regarding their introduction is available.

15. *Ameiurus melas melas* (Rafinesque). Northern black bullhead. We have seen no records of the early introduction of this bullhead, unless some were mixed with shipments of the brown bullhead. This fish is now abundant in the Carson River below the Lahontan Dam, and in irrigation canals in the vicinity of Fallon. It occurs also in the lower Walker and Humboldt rivers, and was introduced in 1942 by V. L. Mills into the Reese River, about 10 miles west-southwest of Austin, from near Fallon.

16. *Ameiurus nebulosus nebulosus* (LeSueur). Northern brown bullhead. This species was one of the first fishes introduced into Nevada. According to Jordan and Evermann (1896: 140), *Ameiurus nebulosus* was first introduced into the Humboldt River about 1877. This statement is in agreement with Parker (1879: 3), who wrote that he planted the "Schuylkill River" variety of catfish in Washoe Lake in August 1877 and that in the same year he also stocked the Truckee, Carson, and Humboldt rivers. Those planted in the Humboldt River were placed not over 10 miles from Elko and also near Lovelock. Smith (1896: 385) erroneously attributed Parker's "Schuylkill catfish" to a different species, *Ictalurus catus,* because the common name "Schuylkill" was originally applied to that species. However, the California commissioners misapplied this common name to *nebulosus,* as shown in Smith (1896: 383), and apparently they passed the error on to Parker. The subsequent accounts (Smith, 1896: 385) of the remarkably rapid increase of the catfish introduced by Parker and of their size (1 to 1½ pounds) indicate without question that the species which became established was *Ameiurus nebulosus.*

Within two years the fish introduced by Parker had increased to such numbers that "other waters were stocked from the supply furnished in Washoe Lake" (Mills, 1891: 6). Federal shipments of

4,800 individuals of this and possibly other species were made to Nevada between 1908 and 1935.

This bullhead is rather abundant in the lower Humboldt, Truckee, Walker, and Carson Rivers and in Pyramid Lake (Snyder, 1917: 85; Hall, 1925: 158; Bond, 1940: 247). Some of the catfish (*Ameiurus*) recorded by Alcorn (1943: 35-36) from the Fallon area are probably of this species. This bullhead was also taken in Hiko Spring, Pahranagat Valley, Lincoln County, in August 1938. It is especially abundant in sloughs and reservoirs where it attains a length of one foot or more.

Poeciliidae (Top Minnows)

17. *Gambusia affinis affinis* (Baird and Girard). Western mosquitofish. This little viviparous fish, now one of the most widely distributed species in the world, was introduced from the vicinity of Los Angeles into the lower Carson River about 1934, by J. H. Kispert (personal interview). Vernon L. Mills told us that he also brought in a stock from the Sacramento Valley in 1934 or 1935. From Fallon they have been transplanted to Lyon and Douglas counties. The mosquitofish is also common in the Moapa River and along the shore of Lake Mead near the mouth of the Moapa River (observations of 1938-1942—in the last year by Carl L. Hubbs). Moffett (1943: 182) has recorded this fish from Lake Mead. A large sample was collected by Hubbs from a spring about 6 miles southwest of Las Vegas, Clark County, in August, 1938. This species was abundant in the outflow of Hinds Hot Springs, about 10 miles north of Wellington, Lyon County, in August, 1942. It does well in the many sloughs and shallow drainage ditches in the Fallon area where the people of that region consider it valuable in controlling mosquitoes and gnats and as food for largemouth bass and other game fishes.

Percidae (Perches)

18. *Perca flavescens* (Mitchill). Yellow perch. The earliest record of introduction into Nevada of this well known species is 1930, when 27 yellow perch were planted in the West Carson River near Genoa (Anonymous, 1931: 23, 37). This same report stated that 100 yellow perch, 5 to 6 inches long, were on hand at Verdi for distribution. Later reports made no mention of these fish. In 1930-1931, 150 fish were sent to applicants in Nevada (Leach, 1932: 683).

This species and the Sacramento perch (a true sunfish) have often been confused. The yellow perch is now common in Lahontan Reservoir and the lower Carson River drainage.

Centrarchidae (Sunfishes)

19. *Micropterus dolomieu dolomieu* Lacépède. Northern smallmouth black bass. According to Smith (1896: 443), this species was first stocked in 1888 in Carson River, Washoe Lake, and a private reservoir

near Carson City. The attempted introduction was apparently unsuccessful and the species has been mostly replaced by the largemouth bass. The report of the Nevada Fish Commission (Anonymous, 1909: 11-12) made no mention of the smallmouth bass even though it gave a list of introduced bass and trout occurring in the state. This report mentioned only "Bass (Wide Mouth) *Micropterus salmoides.*" The first account of the smallmouth bass in reports of the Nevada Fish Commissioner or the Nevada Fish Commission was for 1913, when 400 were sent to Stone Cabin, Nye County, on August 12, 1911 (Anonymous, 1913: 32). In this same report "Black-bass" are listed in the same column with, but under, "Small-mouth." This may indicate that all the black bass in this column are smallmouth. If so, smallmouth bass were planted in the Humboldt River near Winnemucca and Comins Lake, White Pine County, in October, 1911.

In 1885 Parker wrote, ". . . . the species I have introduced which are now so plentiful and popular originally came from Lake George, New York. For a few years an erroneous opinion was entertained by many that it was the Sacramento perch but on comparing ours, weighing from three pounds, with the river perch the difference was apparent." This is the "white bass" of which he speaks. The true white bass is *Lepibema chrysops,* but, according to Greeley (1930: 72), only smallmouth bass occur in Lake George. Parker may have introduced yet another kind of fish but we are unable to identify his "white bass" and refer it tentatively to *Micropterus.*

Dr. Hubbs reports seeing this species along the shore of Lake Mead, near the mouth of Moapa River, on July 28, 1942. So far as known, this is the only recent record of smallmouth black bass in Nevada.

20. *Huro salmoides* (Lacépède). Largemouth black bass. It is not known when this fish was first introduced into Nevada. Cary (1889: 4) stated that black bass were planted in Washoe Lake and in the Carson River in 1887-1888. These fish were obtained from the Spring Valley Water Company of San Francisco, California. Although black bass were frequently mentioned in the early reports, no mention was made of the species involved. Many persons associate the name black bass with *Micropterus dolomieu,* the smallmouth bass, but after reading reports of the Nevada Fish Commissioner and Nevada Fish Commission, there appears to be no confusion here. The earliest publication (Anonymous, 1909: 6, 20) which distinguishes between the two species of bass indicated that 600 "Black Bass (Big Mouth)" were obtained from the California Fish Commission and along with 1,200 adults seined from two ponds near Reno were distributed in Esmeralda, Douglas, Lander, Washoe, Elko, White Pine, Churchill, Humboldt and Lyon counties in 1907 and 1908. Largemouth bass have been abundant in many parts of Nevada since 1910, and perhaps since 1900. During the period 1909-1941, 195,050 eggs and fish were sent by the federal government to Nevada. In the year 1939 alone, 80,000 fingerlings were planted in Lake Mead (Leach, James, and Douglass, 1940: 572).

In the same year 295 largemouth bass were transferred from the California State Central Valleys Hatchery to the State of Nevada (Anonymous, 1941b: 88-89).

This bass is now common in the lower portions of the Walker, Carson, Truckee, and Humboldt rivers. It is known also from the Colorado River in Lake Mead and below Boulder Dam (Moffett, 1942: 82; and 1943: 182), and in Moapa River.

21. *Lepomis cyanellus* Rafinesque. Green sunfish. In 1939, 300 green sunfish were transferred from the California State Central Valleys Hatchery to the State of Nevada (Anonymous, 1941b: 88-89). We have found no other record of introduction and no statement is available concerning the disposition of these fish. The green sunfish may well have been introduced along with or in place of bluegills, by error in identification.

Two specimens of this species were collected by Vernon L. Mills on May 25, 1943, from the Carson River at Coleman Dam, 2 miles northwest of Fallon. It was taken also in the Virgin River, Clark County, near the Utah border (September, 1938), in Moapa River (1942), and was seen by Carl L. Hubbs (July 28, 1942) along the shore in Lake Mead, near the mouth of Moapa River. Since this species is a serious competitor and does not grow to a large size, its further spread is not to be recommended.

22. *Lepomis macrochirus macrochirus* Rafiinesque. Common bluegill. In 1909-1910, 150 fingerlings, yearlings, and adults of this species were planted in Olsen's Lake at Ely (Anonymous, 1911a: 102). This is the earliest record of introduction into Nevada which we have seen. In 1918-1919, 150 fish were stocked in Cottonwood Cañon Creek, near Fallon (Leach, 1920: 69). It is not known definitely that these fish were bluegills but presumably they were. Another plant was made in 1929-1930, and 640 fish, 4 to 7 inches long, were placed in the West Carson River near Genoa in 1930 (Anonymous, 1931: 23-37). Introductions of bluegills have been made into the lakes and reservoirs along the Carson, Humboldt, and Walker Rivers and in many other localities within recent years. According to a letter from O. Lloyd Meehean, the 280,000 sunfish sent to Nevada in 1940 and 1941 (Leach, James, and Douglass, 1941: 569, 603; 1942: 10, 24; and 1943: 14, 25) were of this species, and most if not all of those shipped between 1924 and 1938 were also bluegills.

One specimen was taken on January 28, 1943, from the stomach of an American merganser collected from the lower Carson River, where bluegills apparently are not abundant. We have not seen specimens from elsewhere in the state, although this species is common in Lake Mead (Moffett, 1943: 182).

23. *Archoplites interruptus* (Girard). Sacramento perch. This species, along with catfish, was one of the first exotic fishes planted in Nevada. Parker (1879: 3) stated that he stocked "Washoe Lake, in 1877, with Sacramento River Perch." Also, he "distributed in 1880

catfish and Sacramento river perch in Washoe, Humboldt, Churchill, Lander, Eureka, and Elko Counties" (Parker, 1881: 5).

According to Sumner (1940: 220), this species was introduced into Pyramid Lake in 1889 or 1890. It is quite likely, however, that the plants made in 1877 included Pyramid Lake as Mills (1891: 5) stated that "Walker, Pyramid, and Washoe Lakes are now fully stocked with Sacramento river perch." He wrote further, "They grow to about four pounds weight. . . . As yet but few have reached the weight named, but every year shows their increase in size and numbers."

Sacramento perch are rather common in the drainages of the lower Carson and Truckee rivers and in Walker, Washoe, and Pyramid Lakes (Snyder, 1917: 86; Hall, 1925: 158; Bond, 1940: 247; and Alcorn, 1943: 35-36). A sample of this species was taken in Big Blue Spring, on the west side of Big Smoky Valley, Nye County, in August, 1938. It was also common at that time in a lowland slough at Lusetti Ranch, about 16 miles north of Ely. This species is native to California.

24. *Pomoxis nigro-maculatus* (LeSueur). Black crappie. Although we have no specimens of this fish from waters in Nevada, it is known to occur in Lake Mead (Moffett, 1943: 182) and crappies have been introduced into the state on several occasions since 1924. Its inclusion in this list is therefore justifiable. In the reports of introductions, the U. S. Bureau of Fisheries listed only "crappie," a name which includes the white crappie (*Poxomis annularis*) as well as *P. nigro-maculatus.* Five hundred crappies were liberated in the West Carson River near Genoa in 1930 and 250, 3 to 5 inches long, were on hand at Verdi for distribution in Nevada in 1930. Later reports made no mention as to the distribution of these fish (Annonymous, 1931: 37). A planting of 2,200 was made in 1924-1925; 750 in 1930-1931; and 500 in 1932-1933. No data are available regarding the fate of these plants. The record for Lake Mead is based on a single specimen collected by R. K. Grater on September 12, 1940, at Temple Bar, Arizona, and deposited in the museum of the Boulder Dam National Recreational Area. This specimen was examined by the senior author through the courtesy of Superintendent Robert H. Rose.

II. Species Unsuccessfully Introduced

Thymallidae (Graylings)

1. *Thymallus signifer tricolor* Cope. Montana grayling. According to Leach, James, and Douglass (1942: 10; and 1943: 6) 50,130 eggs of this species were sent to the Nevada Fish and Game Commission in 1941.

By inquiry to the U. S. Fish and Wildlife Service, we learned that these eggs were shipped from Yellowstone Park and received by the Elko County Fish Hatchery at Ruby Valley, Nevada, on June 20, 1941. Mr. Don Griffith, Hatchery Superintendent, writes in a letter

dated January 9, 1944, that 15,000 of the original 50,000 eggs were planted in a large spring near the hatchery, and that part of this planting may have survived as the spring empties into Ruby Lake. However, he and Mr. Herbert Dill, Refuge Manager of the Ruby Lake National Wildlife Refuge, have no evidence that this initial plant was successful. Another attempt to establish grayling is planned for a later time.

Mr. W. A. Dill has called our attention to a publication (Anonymous, 1907) in which the statement is made (p. 43) that fry hatched in California from a shipment of Montana grayling eggs received in 1906 were planted, among other places, "... in the Tahoe region ...". It is therefore possible that grayling were planted on or near the Nevada-California line about 1906.

No characters have been found to distinguish the Montana and Michigan grayling and therefore both are referred to the same subspecies.

Clupeidae (Herrings)

2. *Alosa sapidissima* (Wilson). Common shad. During 1884, 1885, and 1886, relatively large plantings of shad were made in the Colorado River in a vain effort to establish this species (Smith, 1896: 406-407). The introductions were made at "The Needles," Arizona, probably about 15 miles below the present town of Needles and only a short distance below the Nevada boundary. Hence it is assumed that some of these fish once occurred in that portion of the Colorado which marks the southern border of Nevada. Apparently none of the fish liberated have ever been recaptured and no later plants have been made.

Coregonidae (Whitefishes)

3. *Coregonus clupeaformis clupeaformis* (Mitchill). Great Lakes whitefish. According to Smith (1896: 394), this fish was introduced into Lake Tahoe in 1877 and again in 1879. Parker (1879) : 5) wrote that the U. S. Fish Commissioner shipped 250,000 Lake Michigan whitefish spawn to Nevada in February, 1877, but the spawn, on arrival, "was found to be literally cooked," and a total loss. During the season of 1880, the U. S. Fish Commission sent 25,000 eggs to Eureka, but no records of hatching and distribution are available. Results of later introductions were apparently nil and the species has not been taken in subsequent years.

Salmonidae (Trouts)

4. *Salmo salar sebago* Girard. Landlocked salmon. This is the subspecies of Atlantic salmon propagated in Maine. It was reported to be formerly abundant in Nevada after its early introduction into Lake Tahoe in 1881 and into the Truckee and Carson rivers in 1883 and 1891 (Smith, 1896: 431). Mills (1891: 7) reported that he received 25,000 eyed ova of this fish on March 5, 1889, from the U. S. Fish Commissioner. He does not say where they were planted after hatch-

ing. The last shipment of eggs was received at Carson City on March 7, 1892. This species has not been recorded in recent years.

5. *Salmo clarkii stomias* Cope. Greenback cutthroat trout. During the season of 1892-1893, 4,925 adults and yearlings of cutthroat trout were planted in the Humboldt River near Elko, Nevada (Worth, 1895: 132). The only trout of this species (then called *Salmo mykiss*) propagated by the U. S. Fish Commission during the fiscal year 1893 were raised at the Leadville Station, Lake County, Colorado. Worth (1895: 116) indicated that the stock came from streams and lakes in the region (presumably solely from the Arkansas River drainage). This subspecies, originally described from the South Platte River, was common in 1889 in the upper tributaries of the Arkansas River and in Twin Lakes, Lake County, Colorado (Jordan, 1891: 12-13). Another form, the yellowfin cutthroat trout (*Salmo clarkii macdonaldi*), also occurred at that time in Twin Lakes, but the records given by Worth clearly indicate that these two fish were handled separately. It is, however, entirely possible that *macdonaldi* may have been included in the shipment to Nevada or even that another subspecies (such as the Colorado River cutthroat trout, *Salmo clarkii pleuriticus*) was introduced. The available evidence points most logically to *stomias*. Whatever form was planted evidently either did not become established or was thoroughly intermixed (and thus largely excluded) by crossing with the then abundant native cutthroat trout, *Salmo clarkii henshawi*.

6. *Salmo gairdnerii gairdnerii* Richardson. Columbia River steelhead trout. This subspecies is presumably the fish introduced in 1904-1905 and 1908-1909 under the name of steelhead trout, and again during the fiscal years 1923 and 1924 under the name of steelhead salmon. We have seen no specimens referable to this subspecies.

7. *Salmo agua-bonita* Jordan. Golden trout. Shebley (1919: 38) reported that, "A shipment of golden trout was planted in Lake Tahoe. . .". This planting was made in 1918. During the summer of 1919, 250,000 eggs of the golden trout were shipped from the Mount Whitney Hatchery in Owens Valley, California, to the Lake Tahoe Hatchery. "The resulting fry were carefully reared and planted in the streams flowing into the lake, where conditions appeared to be most favorable for them. If the golden trout thrive in the waters of Lake Tahoe, it will mean much to the anglers of the state, who enjoy the fishing in this region." (Shebley, 1921: 33).

So far as is known, no golden trout have since been caught in Lake Tahoe or in the Truckee River below the lake, where some plants may also have been made.

Mr. Dill kindly supplied the information on golden trout.

8. *Oncorhynchus keta* (Walbaum). Chum or dog salmon. During the fiscal year 1939, 252,000 eggs of this species were sent by the Federal Government to the Nevada Fish and Game Commission (Leach, James, and Douglass, 1940: 565). These fish were successfully hatched and planted in 1939 as follows: 200,000 in Churchill County (probably Lahontan Reservoir), 30,000 in Mineral County (probably Walker

Lake), and 10,000 in Washoe County (probably Truckee River) (Anonymous, 1941a: 15). No records of the occurrence of this species in the state are known and none are to be expected.

9. *Oncorhynchus tshawytscha* (Walbaum). Chinook or Quinnat salmon. In March 1879, 250,000 eggs of this species were sent from the hatchery on McCloud River, California, to Nevada. Of these, 50,000 were lost in hatching and transportation so that only 200,000 young fish were actually introduced. Of this number 190,000 were distributed from Reno into Truckee River and 10,000 from Carson City into Carson River (Smiley, 1884: 835, 883). One lot of "Royal Chinook spawn" was received by the Nevada Fish Commission on October 1, 1908. A second lot of 100,000 of the spawn of these fish was received on October 28, 1909, and a third shipment of 100,000 spawn arrived on November 4, 1910. All of these three shipments were donated to the State of Nevada by the State of Oregon (Anonymous, 1911b: 12, 13). After hatching they were planted in Tahoe, Pyramid, and Walker Lakes, and in the Truckee River. Although Snyder (1917: 79, 85) reported the capture of a king salmon in 1911 in the Tahoe region, the plants were obviously predestined to failure.

10. *Oncorhynchus kisutch* (Walbaum). Silver or Coho salmon. This member of the Pacific salmons was planted in the lower Truckee River on June 27, 1913 (Snyder, 1917: 85) from a shipment of 50,000 eggs sent to Verdi during 1912-1913. At the same time, 50,000 eggs were received at Carson City and plants were presumably made in the Carson River. This plant met with no more success than the previous attempts to establish species of *Oncorhynchus*.

11. *Oncorhynchus nerka* (Walbaum). Sockeye or red salmon. In 1936, 60,000 of these fish were distributed in Churchill County (Lahontan Reservoir) and 40,000 in Mineral County (Anonymous, 1936: 12). In the fiscal years 1936-1938, inclusive, 280,000 were distributed to Churchill County, 45,000 to Lyon County, and 70,000 to Mineral County (Anonymous, 1938: 17). In 1938 an additional 170,000 were sent to Churchill County and 100,000 were distributed in Douglas County (Anonymous, 1941a: 15). We have seen none of these specimens and the species is unknown to fishermen in the area.

CYPRINIDAE (MINNOWS)

12. *Tinca tinca* (Linnaeus). Tench. In February 1885, 20 individuals of this European minnow were sent to a private applicant in Virginia City (Smith, 1896: 403). No other record of introduction is known to us and this species has never been recorded from any waters of Nevada.

CYPRINODONTIDAE (KILLIFISHES)

13. *Cyprinodon nevadensis* Eigenmann and Eigenmann. Amargosa pupfish. Between December 31, 1940, and February 18, 1941, 20 specimens of a *Cyprinodon* collected near Las Vegas were sent for identification to the University of Michigan Museum of Zoology. At first they were believed to represent an undescribed form, but on thorough

study their identity with *nevadensis* became certain. This species is confined to the Amargosa River basin of eastern California and southwestern Nevada (Miller, 1943). The specimens were all taken from a "spring" on the Las Vegas golf course in Clark County. An intensive search for additional specimens was made at this locality in October, 1942, but none could be found. The so-called spring is a seepage area fed in part by artesian overflow and in part by overflow from ponds at the Las Vegas Station of the U. S. Fish and Wildlife Service, just to the west. Presumably, this small species was introduced from the Amargosa basin, California, as a forage fish for bass and sunfish propagated at the station.

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A PRE-IMPOUNDMENT BOTTOM-FAUNA STUDY OF CHEROKEE RESERVOIR AREA (TENNESSEE)[1]

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ABSTRACT

Pre-impoundment bottom-fauna data from five stations are presented for the Cherokee Reservoir area, Tennessee. Production was found to be much lower in the deep-water pools than in the shallow-water riffle areas. In the riffle areas the two taxonomic groups, Trichoptera and Diptera, made up 93.3, 81.4, and 92.8 per cent of the total population while the Trichoptera and Sialidae comprised 69.3, 80.0, and 88.4 per cent of the total volume at three different stations. The gradual increase in volume over a period of 3 months at the most productive station was concluded to be due almost entirely to the increment in numbers of Trichoptera rather than to the growth of individual organisms.

Pollution of the Holston River by sewage and industrial wastes was an important factor that limited production of bottom organisms. Physico-chemical data are given and are correlated with bottom-fauna data to support the contention that pollution resulted in a decrease in the fauna upstream toward the source of pollution. It is concluded that impoundment of the Holston River by Cherokee Dam will reduce the effects of pollution in the reservoir area.

It is expected that the principal components of the Holston River bottom fauna will not survive impoundment and that whatever organisms do survive impoundment or invade the reservoir area, the total production per unit area will not be as great in the reservoir as it was in the original river channel. Comparisons between the pre-imopundment bottom fauna of the Cherokee and Watts Bar Reservoir areas point to the fact that while Cherokee is the more productive, the bottom fauna at Watts Bar has a better chance of surviving impoundment, and hence, that Watts Bar Reservoir will probably produce more bottom organisms than did the original river. This contrast is a result of environmental differences between the habitats of the two areas.

INTRODUCTION

Bottom-fauna investigations have become an integral part of comprehensive fishery-management programs. They are made for the purpose of determining the relative amount of bottom fauna available as potential fish food and the role of these organisms in the food-chain economy of a body of water. The importance of such studies is emphasized when an attempt is being made to balance fish populations through various control measures. For example, it would be futile to foster production of bluegills (bream), although they are excellent

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pan fish, in certain of the storage-reservoir lakes of the Tennessee Valley, since this species is essentially insectivorous, and comparatively few aquatic insects occur in these storage reservoirs. Eschmeyer (1940) pointed out the slow growth of bluegills in Norris Reservoir and mentioned that it might be due to the paucity of insect life in the lake. From limited observations (Wiebe, 1938) it is known that aquatic insects are relatively scarce in Norris Reservoir and it is expected that upon examination, other storage-type reservoirs will be similar to Norris in this respect.

It is fully realized that the omission of the statistical approach from any modern, quantitative biological study may immediately open the way toward criticism of the work. Often such criticism may be warranted. Nevertheless, certain kinds of useful biological information which serve a specific purpose to the problem at hand can still and, at times, must be obtained without the useful tool of statistics. Conditions and factors within an environment being studied may be so variable and numerous that to cope with all of them from the mathematical viewpoint would slow the work to a point where the information, even though accurate to a high degree, would no longer be needed for the original purpose intended. This is especially true of the numerous, large, artificial lakes with areas of 500-256,000 acres which are now found from one end of the Tennessee Valley to the other. To sample adequately even one of these lakes would require a large number of workers and years of labor.

Concession is also made of the fact that a true measure of the availability of fish food is not obtained merely from averages in bottom-fauna data, since the presence alone of an animal as a component of the fauna does not necessarily mean that it can or will serve as food for fish. Here again, it may be pointed out that both sufficient time and manpower must be available when an investigation of this nature, which involves so many variables, is undertaken. The use of such amounts of time and manpower would probably not be justified until fish management is better able to interpret bottom-fauna data in terms of the potential yield of fish and until many other fishery problems have received more consideration.

Biological research from the quantitative angle does not in all situations lend itself to statistical analysis. Yet, this fact does not invalidate the results obtained or conclusions drawn from such data. Indications and trends are often as useful as absolute values. In instances where the problem at hand obviously includes innumerable channels of possible investigation, it is difficult to lay aside for future reference those intricate lateral ramifications which tend, by their intriguing but purely scientific aspect, to divert the practical worker from the purpose of the major problem. With these facts in mind emphasis

is being placed on the principal problem of the TVA fishery-management program, namely, the control of fish populations in large bodies of impounded water with a view to the possibility of a greater production of desirable species. The present study is offered as a contribution toward this end.

The multi-purpose impoundment by the Tennessee Valley Authority of the rivers throughout the Tennessee Valley has resulted in drastic changes of the pre-impoundment aquatic environment. The present study of the Cherokee Reservoir area was undertaken with a two-fold purpose in mind: (1) To determine the qualitative and quantitative composition of the bottom fauna both before and after impoundment; and (2) to compare such findings with similar data from Watts Bar Reservoir (Tennessee). That portion of the Holston River now flooded by Cherokee Reservoir was decidedly different from that part of the Tennessee River which is now covered by Watts Bar Reservoir. It is expected that the effects of impoundment upon the bottom fauna of these two types of streams will be in direct contrast to each other. For this reason post-impoundment bottom-fauna studies of Cherokee and Watts Bar Reservoirs are planned.

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Stations

Cherokee Reservoir (Table 1) is located on the Holston River about 50 miles above the mouth and lies approximately 25 miles due east of and is parallel with Norris Reservoir to which it is very similar. The Holston River becomes confluent with the French Broad River just above Knoxville, Tennessee, where the two join to form the Tennessee River. A general description of the Holston River has already been given by Smith and Miller (1943). The final closure of Cherokee

Dam and impoundment of the water took place early in December 1941.

TABLE 1.—*Morphometric data on Cherokee Reservoir. All elevations are given in feet above sea level.*[1]

Original river area	2,500	acres
Reservoir:		
Area {Maximum, at elevation, 1,075	31,100	acres
Area {Minimum, at elevation 980	4,700	acres
Length, at elevation 1,075	58.5	miles
Shoreline, at elevation 1,075	380	miles

[1]Data from Cherokee Project, TVA Water Control Planning Department, September, 1940.

Five principal stations were chosen along the course of the river. Station I was located at Surgoinsville, Tennessee (Mile 118.3); Station II, at Burem Bridge (Mile 109.9) just above Rogersville, Tennessee; Station III, at the bridge (Mile 104.3) for Tennessee State highways, 66 and 70, south of Rogersville; Station IV (Mile 74.5), near the bridge for U. S. Highway 25E; and Station V, just above the mouth of Honey Creek (Mile 65.1), about 12.5 miles above the dam site. With exception of Station I, all stations were located within that portion of the Holston River which is now included by Cherokee Reservoir.

The stream bed of the Holston River consisted almost exclusively of limestone and shale. The stream was relatively shallow, contained many riffle[2] areas, with alternating pools which normally reached a depth of about 10 feet. Stations I and IV were located in pools while Stations II, III, and V were in riffle areas.

The bottom of the pool at Station I consisted of bed rock overlain with a deposit of black, organic and mineral debris and mud. At Station IV the bottom was composed of a fine sand and organic and mineral silt overlying bed rock. In the riffle areas of the stream the bottom was made up chiefly of medium-sized (2-4 inches, diameter) to large (4-10 inches, diameter) rocks. That type of bottom usually described as gravelly was relatively uncommon. Parts of the river bottom consisted of flat, smooth, shelving rock. In riffles, higher aquatic plants, such as, *Valisneria* and *Potamogeton* spp. were present over limited areas. Such plants were common at Station II, and were totally absent at Stations III and V, but occurred in various places along the stream between Stations IV and V.

METHODS

At the two deep-water stations, I and IV, collections were made with an unweighted Petersen dredge that covered an area of 0.82 square foot. Two or three hauls were taken per sample at any given depth. Attempts to take samples, especially in mid-stream, were often unsuccessful because of the bed rock encountered. A 30-mesh screen was used for washing and concentrating samples in the field; the residue

[2]Riffles and shallow flats are referred to collectively in this paper as riffles. Data collected from both areas are treated as a unit.

was then preserved with 10-per-cent formalin. Collecting at Stations II, III, and V was accomplished with a Surber sampler (Surber, 1937) which covered an area of 1 square foot, and the residue was preserved as described above. Animals from 1 square foot constituted one sample.

A total of 261 bottom samples was secured between July 18 and November 24, 1941. Due to high-water conditions that prevailed early in the summer of 1941, sampling of the riffles was not begun until August 14. Most of the work was concentrated at Station V where 157 samples were taken. A series of 20 samples was collected on October 30 from eight different areas distributed at random between Stations IV and V.

The salting-out technique, described previously (Lyman, 1943), was used in the laboratory to separate organisms from debris; the methods and equipment that were used to measure volumes, after the organisms were sorted to major taxonomic groups, were also discussed (*loc. cit.*).

Local and Seasonal Differences in the Abundance and Composition of the Bottom Fauna

The bottom fauna in the pools (Tables 2 and 5) of the Holston River was relatively scarce as compared to that found in the riffle areas (Tables 3, 4, and 6). The average total number for Stations I and IV was 19.58, and the average total volume[3] was 0.06, as compared to the numbers of 424.28 at Station V, 103.20 at Station III, and 150.54 at Station II, and volumes of 1.82, 0.25, and 0.39 at the same stations, respectively. It may be noted that the total number and volume are somewhat higher at Station II than at III. As has been mentioned above, rooted aquatic plants were present in the area of Station II but were absent from Station III. This fact may account for the somewhat greater productivity of the Station II area. At both Stations I and IV (Tables 3 and 5) the Oligochaeta and Diptera were by far the most important groups. The slightly greater average numbers and volumes at Station I were probably due to seasonal differences, since the samples were collected in October and November, a period of high production, while those from Station IV were taken in July and August, a period of low production. However, this difference might also be a result of variation in the type of bottom at the two stations. Certain qualitative differences in fauna are shown by the tables, but since the numbers and volumes are quite small, they become relatively unimportant.

A qualitative and quantative examination of the data from Stations II, III, and V (Tables 3, 4, and 6) shows that essentially the same groups of organisms were present, although in various degrees of importance, at each of the three stations. At Station II the total number of different groups represented was 10, while 14 were found

[3]All volumes in this paper are given in cubic centimeters. Numbers and/or volumes are per square foot.

TABLE 2.—*Average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station I, Holston River, at Surgoinsville, Tennessee. Based on 28 bottom samples (2-3 hauls per sample) taken with a Petersen dredge, October 16 to November 24, 1941.*

Organisms	Number	Percentage of total number	Volume	Percentage of total volume
Oligochaeta (Earthworms)	6.42	26.4	0.05	55.6
Hirudinea (Leeches)	0.04	0.2	0.01	11.1
Anisoptera (Dragonflies)	0.19	0.8	0.01	11.1
Zygoptera (Damselflies)	0.02	0.1	Trace	Trace
Coleoptera (Beetles)	0.12	0.5	Trace	Trace
Lepidoptera (Aquatic caterpillars)	0.02	0.1	Trace	Trace
Diptera (True flies)	17.44	71.9	0.02	22.2
Total	24.25	100.0	0.09	100.0

TABLE 3.—*Average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station II, Holston River, Cherokee Reservoir area, Tennessee. Based on 13 square-foot bottom samples taken with a Surber sampler, October 17 to November 10, 1941.*

Organisms	Number	Percentage of total number	Volume	Percentage of total volume
Oligochaeta (Earthworms)	7.39	4.9	0.05	12.8
Hirudinea (Leeches)	0.08	0.1	Trace	Trace
Sialidae (Dobson-flies)	0.38	0.2	0.19	48.8
Ephemeroptera (Mayflies)	0.08	0.1	Trace	Trace
Anisoptera (Dragonflies)	0.38	0.2	0.02	5.1
Zygoptera (Damselflies)	0.08	0.1	Trace	Trace
Coleoptera (Beetles)	0.92	0.6	Trace	Trace
Trichoptera (Caddisflies)	19.00	12.6	0.08	20.5
Lepidoptera (Aquatic caterpillars)	0.69	0.5	Trace	Trace
Diptera (True flies)	121.54	80.7	0.05	12.8
Total	150.54	100.0	0.39	100.0

TABLE 4.—*Average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station III, Holston River, Cherokee Reservoir area, Tennessee. Based on 39 square-foot bottom samples taken with a Surber sampler, October 13 to November 12, 1941.*

Organisms[1]	Number	Percentage of total number	Volume	Percentage of total volume
Nematoda (Roundworms)	0.03	Trace	Trace	Trace
Oligochaeta (Earthworms)	2.33	2.3	Trace	Trace
Hirudinea (Leeches)	0.08	0.1	Trace	Trace
Hydracarina (Water mites)	0.03	Trace	Trace	Trace
Sialidae (Alder flies)	0.95	0.9	0.12	48.0
Ephemeroptera (Mayflies)	0.33	0.3	Trace	Trace
Anisoptera (Dragonflies)	0.10	0.1	Trace	Trace
Zygoptera (Damselflies)	0.10	0.1	Trace	Trace
Plecoptera (Stoneflies)	0.05	Trace	0.01	4.0
Coleoptera (Beetles)	15.23	14.8	0.02	8.0
Trichoptera (Caddisflies)	33.59	32.6	0.08	32.0
Lepidoptera (Aquatic caterpillars)	0.05	Trace	Trace	Trace
Diptera (True flies)	50.33	48.8	0.02	8.0
Total	103.20	100.0	0.25	100.0

[1]Decapoda are excluded from the above data since they occurred only in samples from this one station and while the number per square foot was low (0.10), the volume per square foot was high (0.35). Including these organisms as part of the above table, although it is conceded that they are undoubtedly a part of the fish-food picture, would render the data unusable for comparative purposes with data from Stations II and V.

TABLE 5.—*Average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station IV, Holston River, Cherokee Reservoir area, Tennessee. Based on 4 bottom samples (2 hauls per sample) taken with a Petersen dredge, July 18 to August 21, 1941.*

Organisms	Number	Percentage of total number	Volume	Percentage of total volume
Oligochaeta (Earthworms)	9.42	63.2	0.04	100.0
Sialidae (Alder flies)	0.10	0.7	Trace	Trace
Ephemeroptera (Mayflies)	0.30	2.0	Trace	Trace
Anisoptera (Dragonflies)	0.41	2.8	Trace	Trace
Trichoptera (Caddisflies)	1.02	6.8	Trace	Trace
Diptera (True flies)	3.66	24.5	Trace	Trace
Total	14.91	100.0	0.04	100.0

TABLE 6.—*Average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station V, Holston River, Cherokee Reservoir area, Tennessee. Based on 157 square-foot bottom samples taken with a Surber sampler, August 14 to November 13, 1941.*

Organisms	Number	Percentage of total number	Volume	Percentage of total volume
Turbellaria (Flatworms)	0.24	0.1	Trace	Trace
Nematoda (Roundworms)	0.17	Trace	Trace	Trace
Oligochaeta (Earthworms)	2.39	0.6	0.10	5.5
Hirudinea (Leeches)	0.01	Trace	Trace	Trace
Hydracarina (Water mites)	0.01	Trace	Trace	Trace
Sialidae (Dobson-flies)	2.07	0.5	0.31	17.0
Ephemeroptera (Mayflies)	14.97	3.5	0.03	1.6
Anisoptera (Dragonflies)	0.10	Trace	Trace	Trace
Zygoptera (Damselflies)	0.69	0.2	0.01	0.6
Plecoptera (Stoneflies)	0.04	Trace	Trace	Trace
Coleoptera (Beetles)	9.81	2.3	0.01	0.6
T ichoptera (Caddisflies)	269.26	63.4	1.30	71.4
Lepidoptera (Aquatic caterpillars)	0.01	Trace	Trace	Trace
Diptera (True flies)	125.01	29.4	0.06	3.3
Total	424.78	100.0	1.82	100.0

at Station V. From the standpoint of numbers, the two taxonomic groups, Trichoptera and Diptera, were far more important than all other groups combined, and comprised 93.3, 81.4, and 92.8 per cent of the total population at Stations II, III, and V, respectively. Diptera were more numerous than Trichoptera at Stations II and III, but at Station V the Trichoptera were the more abundant. From the standpoint of volume the Trichoptera and Sialidae were the most significant groups and comprised 69.3 per cent of the total volume at Station II, 80.0 per cent at Station III, and 88.4 per cent at Station V. At Stations II and III the Sialidae formed a larger proportion of the volume than did the Trichoptera; however, the Trichoptera at Station V made up 71.4 per cent of the total volume while the Sialidae composed only 17.0 per cent. The Diptera, which formed a relatively small proportion of the total volume at all stations as compared with the Trichoptera and/or Sialidae, were most significant at Station II and became progressively less outstanding at Stations III and V. The Oligochaeta constituted a larger percentage of the total volume at Station II than at either of the other stations; the average volume was greatest, however, at Station V. The other organisms listed in the

TABLE 7.—*Comparison of average numbers and volumes (cubic centimeters) of bottom organisms per square foot at Station V with similar data from eight localities between Stations IV and V, Holston River, Cherokee Reservoir area, Tennessee. Based on 10 samples taken at Station V, October 21, 1941, and 20 samples collected between Stations IV and V, October 30, 1941, with a square-foot Surber sampler.*

Organisms	Station V				Stations IV to V			
	Number	Percentage of total number	Volume	Percentage of total volume	Number	Percentage ot total number	Volume	Percentage of total volume
Oligochaeta	2.40	0.3	0.13	3.4	1.75	0.3	0.03	0.9
Trichoptera	477.60	62.3	3.22	83.2	322.40	47.7	2.75	78.1
Ephemeroptera	8.90	1.2	0.02	0.5	16.00	2.4	0.03	0.9
Coleoptera	17.30	2.3	0.01	0.3	17.75	2.6	0.01	0.3
Zygoptera	0.10	Trace	Trace	Trace	0.65	0.1	0.01	0.3
Anisoptera	0.30	Trace	Trace	Trace	0.15	Trace	Trace	Trace
Diptera	257.90	33.6	0.14	3.6	313.60	46.4	0.16	4.5
Sialidae	2.40	0.3	0.35	9.0	3.00	0.4	0.53	15.0
Plecoptera	....	....	....	....	0.35	0.1	Trace	Trace
Nematoda	....	....	....	....	0.05	Trace	Trace	Trace
Hydracarina	0.10	Trace	Trace	Trace	....	....	....	....
Hirudinea	0.10	Trace	Trace	Trace	....	....	....	....
Lepidoptera	0.10	Trace	Trace	Trace	....	....	....	....
Total	767.20	100.0	3.87	100.0	675.70	100.0	3.52	100.0

TABLE 8.—*Seasonal distribution and average size (cubic centimeters) of individuals of the major groups of bottom organisms by months at Station V, Holston River, Cherokee Reservoir area, Tennessee. Based on the following numbers of samples: 74 collected in August, 35 in September, 31 in October, and 17 in November, 1941. Average numbers and volumes (cubic centimeters) per square foot.*

Organisms	August		September		October		November	
	Number	Volume (total & aver'ge)	Number	Volume (total & aver'ge)	Number	Volume (total & aver'ge)	Number	Volume (total & aver'ge)
Trichoptera	46.82	0.14	314.63	1.08	549.68	3.04	632.76	3.83
Size	....	0.0030	....	0.0034	....	0.0055	....	0.0061
Diptera	52.27	0.02	106.06	0.04	222.39	0.11	301.06	0.24
Size	....	0.0004	....	0.0004	....	0.0005	....	0.0008
All others	14.30	0.29	52.60	0.51	49.25	0.71	23.00	0.41
Size	....	0.0203	....	0.0097	....	0.0144	....	0.0178
Total	113.39	0.45	473.29	1.63	821.32	3.86	956.82	4.48

tables need no further comment as they comprise only a small proportion of the total number and volume.

In order to determine the validity of sampling at only one station, and considering it as representative of a large section of the river, a series of 20 samples was collected from eight areas chosen at random along the Holston River between Stations IV and V. Data from these samples were compared with data from samples collected at Station V on comparable dates (Table 7). This comparison shows that Station V may be regarded as typical. The same groups of bottom organisms, with insigficant minor exceptions, were found between Stations IV and V as occurred at Station V. The Trichoptera and Diptera formed 95.9 per cent of the total average number at Station V, and 94.1 per cent in the area between Stations IV and V. From the standpoint of

average volume the Trichoptera and Sialidae comprised 92.2 per cent of the total at Station V, and 93.1 per cent between Stations IV and V. In total average number and volume, Station V was somewhat the more productive which, as will be shown below when pollution is discussed, might be expected.

A definite, gradual increase in the total average numbers and volumes (Table 8) occurred in the fauna present at Station V between August 14 and November 13. This change appears to represent the combined effects of increase in numbers and growth of individuals—primarily the Trichoptera and Diptera. In these two groups the average size of an individual doubled during the three months covered by this study, and at the same time, the average numbers of the Trichoptera increased about 14 times while the Diptera increased 6 times. Because of the relatively greater increase in numbers, therefore, it may be concluded that the total increase in volume was due chiefly to the increment in numbers of Trichoptera rather than to growth of the individual organisms. Because of their small size, the Diptera had but little effect on the increase of the total volume, even though the increment in the number of individuals was large.

While no attempt was made to measure numbers and volumes of the various components of the major groups of organisms named in Tables 2-6, notes were kept during the course of the work on the kinds of organisms comprising each of these groups, where identification in certain taxonomic categories was feasible without a too great consumption of time. A summary of such identifications, including all stations, is as follows:

Sialidae—*Corydalus*

Ephemeroptera—Caeninae (*Tricorythodes*), Baetinae

Coleoptera—Elmidae, Haliplidae (*Peltodytes*)

Trichoptera—Hydropsychidae (Hydropsychinae and Macronematinae), Hydroptilidae, Polycentropidae.

Lepidoptera—Nymphulinae (*Paraponyx*)

Diptera—Chironomidae (Orthocladiinae (*Spaniotoma*) and Tanypodinae), Empididae (*Hemerodromia*), Rhagionidae (*Atherix*), Tipulidae, Simuliidae (*Simulium*), Culcidae (*Chaoborus*).

Identifications of Trichoptera, Elmidae (Coleoptera), and Plecoptera were noted by Dendy (1944).

Pollution on the Holston River

The biological and chemical conditions that existed downstream from the sources of pollution demonstrated that Stations I, II, and III were located in the mesosaprobic or polluted zone (Kolkwitz and Marsson, 1909). This zone according to Alexander (1925) is the second step toward purification of grossly polluted waters and is characterized by the presence of higher aquatic plants and by high concentrations of dissolved oxygen and ammonia. The area between Stations IV and V may best be described as located at or near the place of transition

from the mesosaprobic to the oligosaprobic or clean-water zone. Due to the absence of certain organisms indicative of clean water, and the high total nitrogen content of the water, the authors do not consider this area as strictly unpolluted. The septic or polysaprobic zone, which undoubtedly existed nearer the pollutional sources, was not included in this study. However, since the primary reason for this investigation was to obtain, for comparative purposes, information on the relative amount and kinds of fish food available, the pollutional aspects of the problem were given only secondary consideration. For this reason a true oligosaprobic zone was not included as a part of the work.

Pollution of the Holston River was indicated by the following: (1) Information on sewage and industrial wastes; (2) quantitative bottom-fauna data, (3) physico-chemical analyses of the water; (4) the presence or absence of different kinds of bottom organisms; and (5) data on the occurrence and abundance of fish (Smith and Miller, 1943).

Untreated domestic sewage and industrial wastes are emptied into three principal branches of the Holston River (the North Fork Holston, South Fork Holston, and Watauga Rivers) above that portion of the river covered by this investigation. The chief pollutional effluents (Table 9) are produced by various types of industries which are engaged in the bleaching, kiering, dyeing, washing, and finishing of cloth fabrics, the production of paper, and the manufacturing of chemical products. Within the reservoir area proper, two towns, Rogersville, population 2,000, and Morristown, population 8,000, contribute

TABLE 9.—*Sources of domestic sewage and industrial wastes contributing to pollution of the Holston River, Tennessee. Data for 1938 and 1939 (except populations), furnished by TVA Health and Safety Department.*

Location and population of town (1940)	Type of plant or waste
Kingsport, Tennessee (14,400)	Soda pulp and paper (typical). Bleaching, dyeing and finishing of cotton piece goods. Figured and wired rolled glass. Cellulose and chemical products.
Bristol, Tennessee-Virginia (14,000)	Kiering, bleaching, and dyeing. Bleaching and dyeing. Dyeing and finishing. Tanning extract. Soda pulp.
Saltville, Virginia (2,600)	Salt products, ammonia, limestone.
Johnson City, Tennessee (25,300)	Small amount of industrial waste.
Elizabethton, Tennessee (8,500)	Rayon mills.

some small amount of sewage and waste, but this, according to all indications, does not affect the river unfavorably.

It is well known (Ellis, 1937) that sewage and industrial effluents have markedly deleterious effects upon natural biological resources of streams. That the Holston River has been so affected seems to be clearly shown by the bottom-fauna data discussed above, since a decrease in both numbers and volumes of organisms occurred upstream toward

the sources of pollution. Data from Station V and from the area between Stations IV and V emphasize that this portion of the river, many miles below the origin of pollution, has not been affected as much as the areas of Stations II and III.

Examination of data in Table 10 for October and November shows that a general, though small, reduction in bottom organisms occurred at Stations II and III while a definite increase took place at Station V. Under normal circumstances an increment similar to that which occurred at the lower station, rather than a decrease, was to be expected at the two upper stations. The reason for the decrease seems to lie in the fact that the late summer and fall of 1941 were extremely dry with the result that the volume of flow was much lower than normal in the Holston River. From physico-chemical data collected by the Biological Readjustment Division (Table 11) at Stations III, IV, and V in October and November 1941, it appears that because of low water, the effects of pollution were more prominent and, hence, account for the reduction of bottom fauna at the upper stations. The high values of total nitrogen shown by the analyses of the water during October and November indicate definite pollution, even at Station V. This high

TABLE 10.—*Comparison of average numbers and volumes (in cubic centimeters) of bottom organisms per square foot at Stations II, III, and V, Holston River, Cherokee Reservoir area, Tennessee, for October and November, 1941. Samples taken with a Surber sampler.*

Station	October			November		
	Number of samples	Number	Volume	Number of samples	Number	Volume
II	10	174.20	0.40	3	71.66	0.37
III	23	96.35	0.27	16	113.06	0.21
V	31	821.32	3.86	17	956.82	4.48

TABLE 11.—*Physico-chemical data from three stations on the Holston River, Cherokee Reservoir area, Tennessee, and from one station on the Tennessee River, Watts Bar area, Tennessee, 1941.*

Station	Date	Temperature in degrees Fahrenheit	pH	Dissolved oxygen in parts per million	Methyl orange alkalinity in parts per million	Nitrogen in parts per million					Total phosphorus in parts per million[1]
						Organic	NH_3	NO_2	NO_3	Total	
III	Nov. 12	46.0	8.1	9.9	121.0	0.448	6.60	0.070	1.52	8.638	0.03
IV	Oct. 30	58.0	7.9	7.8	123.0	0.384	3.68	0.070	1.20	5.334	Trace
IV	Nov. 13	44.0	8.1	10.8	116.0	0.296	3.80	0.028	1.36	5.484	0.03
V	Oct. 30	60.0	8.2	7.7	100.0	0.224	2.40	0.175	1.84	4.639	Trace
V	Nov. 13	46.0	7.8	10.6	112.0	0.272	3.10	0.077	1.60	5.049	0.04
Watts Bar I[2]	Nov. 18	....	7,6	....	61.0	0.144	0.152	0.002	0.60	0.898	0.03

[1]All determinations for soluble phosphorus were 0.0 p.p.m.
[2]Lyman (1943).

total nitrogen was due primarily to large concentrations of dissolved ammonia. In a broad study of water pollution, Ellis (1937) stated that, "1.5 p.p.m. dissolved ammonia was considered the maximal amount of dissolved ammonia not suggestive of specific organic pollution. In flowing streams 2 to 3 p.p.m. were almost always associated with definite organic pollution and values above 3 p.p.m. in our field studies were always traceable to sewage or factory effluents." On the Holston River dissolved ammonia reached, at least, 6.60 p.p.m. at Station III in November, and at the same time was 3.10 p.p.m. at tion V. It should be pointed out that Ellis (*loc. cit.*) also stated that Ellis and Chipman found "ammonium salts becoming more toxic in more alkaline media." Table 11 shows that the pH of the Holston River averaged about 8.0 during October and November, 1941. According to these same workers certain aquatic organisms under experimental conditions succumbed in 10 days or less to concentrations of 2.5 p.p.m. of ammonia.

A period of low water on the Holston River was probably always accompanied by an increase in the severity of pollution. Data collected at Station I in the spring of 1942 shows that from March 24 to May 4 the concentration of ammonia increased from 0.72 to 4.80 p.p.m. On May 25, immediately following a flood, the concentration dropped to 0.28 p.p.m. The average volume of flow of the Holston River is 4,270 cubic feet per second. During the latter half of March the volume of flow was well over this figure (ammonia low). During April and the forepart of May, however, the volume of flow dropped to an average between 1,000 and 2,000 cubic feet per second (ammonia high), less than one-half the normal flow. As the ammonia increased to 4.80 p.p.m., dissolved oxygen dropped to 5.65 p.p.m. (water temperature 76.0° F.). Ellis (1937) considered that the lower limit of favorable conditions for fish is reached at approximately 5.0 p.p.m. of dissolved oxygen at about 68.0° F. This, of course, does not mean that fish will succumb in water containing 5.0 p.p.m. of dissolved oxygen, but rather that such concentrations approach the lower optimal limit. Under sustained unfavorable conditions no organism can hope to reach or approach its full capacity for growth and reproduction.

Aside from the purely quantitative aspect of the bottom fauna in the Holston River, the presence or absence of certain kinds of aquatic organisms are positively or negatively indicative of specific organic pollution. The relative scarcity of representatives from such groups as, the Ephemeroptera, Odonata, Plecoptera, Tipulidae, and Simuliidae, and the total absence of Mollusca, which are all good indicators of clean-water situations, seem to point without question to pollution of the river as a vital, limiting, environmental factor. Empty shells and fragments of Mollusca were numerous, which fact demonstrates that more favorable environmental conditions had existed in the Holston River. Although the Trichoptera, which made up the most important single group, were composed of members of two subfamilies

that were considered as clean-water forms by Alexander (1925), the writers hold these forms as tolerant, since this group was most abundant at Station V, and yet, was well-represented in the mesosaprobic zone. From a study of pollution in 1941 on the Pigeon River watershed (North Carolina and Tennessee), Hess and Tarzwell (MS—data unpublished) reached similar conclusions with regard to the Trichoptera. The most important group of Diptera was the Chironomidae. Members of this family belonging to the Orthocladiinae were found at Station V while members of the Tanypodinae were more abundant in the highly polluted zone upstream. No representatives usually associated with the polysaprobic zone, such as *Eristalis* and *Psychoda*, were taken.

Smith and Miller (1943) have already reported on the relatively low take of fish from the Cherokee Reservoir area in a comparative pre-impoundment study of the fish population made by means of hoop nets. Mention was made of the fact that fish mortality had at times resulted from pollution and that pollution may have been sufficiently severe at all times to affect the fish population. Reports received by Dr. R. W. Eschmeyer of the Biological Readjustment Division, from fishermen along the Holston River, established the fact that pre-impoundment fishing was definitely better in that part of the river between the dam site and the mouth than it was upstream from the dam site.

Summary and Conclusions Based on a Comparison of Cherokee and Watts Bar Reservoirs

With the completion of pre-impoundment bottom-fauna investigations of two types of reservoirs, Cherokee and Watts Bar, certain valid comparisons may be made that emphasize differences rather than likenesses. This contrast was anticipated, since in the Watts Bar Reservoir area the deep-water type of habitat predominated while the principal type of habitat in the Cherokee Reservoir area was the shallow-water riffle. Moreover, the Tennessee River was broad, turbid, and of sluggish flow as compared with the Holston River which was relatively narrow and clear and was moderately swift.

A faunal resemblance within the higher taxonomic categories existed between Cherokee and Watts Bar; however, analyses of these major groups show that this similarity was superficial rather than actual, for the kinds of organisms comprising the larger groups were, for the most part, totally different in the two areas. From a quantitative aspect it is evident that Station V at Cherokee was far more productive of both numbers and volumes of bottom organisms than Station I at Watts Bar. At Watts Bar the Ephemeroptera (*Hexagenia*) were primarily responsible for the productivity of the area, but at Cherokee the Trichoptera were definitely in the majority. This difference is obviously a result of contrast in habitats. Furthemore, it is worthy of note that the most prolific period for both Cherokee and

Watts Bar came in the fall season while the summer was a period of low production.

Pollution as a limiting factor within the environment was most important in the Cherokee area, especially near the head of the reservoir and farther upstream. Although it is known that pollution did occur in other places on Watts Bar, there was no clear evidence of the effects of pollution in that part of the Tennessee River where the samples of bottom organisms were taken.

Since predictions as to future biological happenings almost always entail a great amount of uncertainty, the authors guardedly make the following prognostications with regard to the effect of impoundment. The most important organism of the deep-water bottom fauna at Watts Bar, ***Hexagenia,*** will survive and undoubtedly thrive under the new conditions brought about by impoundment and, as was previously stated (Lyman, 1943), the shallow-water fauna for the most part will disappear. Reasons for this prediction have already been given (*loc. cit.*).

With the impoundment of the Holston River by Cherokee Dam the natural environment within the reservoir area was drastically changed from absolute lotic to lentic conditions. That such an abrupt modification of the environment would result in elimination within the flooded river channel of almost all of the bottom-dwelling organismsm, was a foregone conclusion. Most certainly the principal component of the bttom fauna, the Trichoptera, could not withstand the change of conditions, since normal currents do not exist in a storage reservoir and dissolved oxygen is absent near the bottom in deep water during most of the year. These forms seem to demand flowing water in order to obtain an adequate food supply (Betten, 1934) and to require high dissolved oxygen.

The question now arises as to the source of the bottom fauna of the reservoir. There appear to be two major possibilities. Almost any large association of different kinds of animal organisms that belong to a specific set of environmental conditions, contains borderline members with a wide range of tolerance. Various members of the Diptera group which inhabited the original river bottom seem to constitute just such examples, and there is good reason to believe that a large proportion of the ultimate bottom fauna of the reservoir will be derived from the Diptera group. Two likely paths of invasion by the river fauna into the reservoir area as a whole exist. A lateral spreading from the original river bottom along with invasion from the main stream or from lateral tributaries into the reservoir; secondly, winged, adult. aquatic insects may enter the reservoir area through the air, deposit eggs in the water, and thereby establish a bottom fauna of the lentic type. This last method would perhaps be the slower. Regardless of what fish-food bottom organisms are produced by Cherokee, it is expected that the numbers and volumes per unit area will not be as large on an average as they were, for example, at Station V or between Sta-

tions IV and V, before impoundment. This expectation is in direct contrast to that for Watts Bar.

As a result of impoundment the effects of pollution will be minimized by dilution of the pollutants within the reservoir area in general. However, the unnatural conditions will not improve in the river above, and the extreme head of the reservoir may still be affected unfavorably even with impoundment. It is felt that a general improvement conducive to greater fish production and better fishing, will be forthcoming within the reservoir area due to the diminution of pollutional effects. Because adverse conditions within the river will remain unchanged, the use of the river by fish from the reservoir will probably be at a minimum.

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SURVIVAL, POPULATION DENSITY, GROWTH, AND MOVEMENT OF THE WILD BROWN TROUT IN CRYSTAL CREEK

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ABSTRACT

A portion of the data accumulated in a 4-year study of the trout of Crystal Creek, New York State, is reported. An annual population inventory of the same 13 sample sections of the stream each September for 4 years provided information on survival, density of fish, growth, movement, and other factors. The percentage survival of the young brown trout of the year (age-group 0) in later years was found to be as follows: Second year (age-group I), 24.1; third year (age-group II), 11.0; fourth year (age-group III), 5.49; fifth year (age-group IV), 1.25; sixth year (age-group V), 0.48. The trout were subject to angling, which accounted for about 15 per cent of the yearly losses of the legal-sized fish. A considerable mortality of the larger-sized trout, for which the cause could not be determined, was observed each year during July.

Hatchery fingerlings planted in September survived to the following September at rates varying from 0.25 per cent to 6.3 per cent (the latter figure is the more reliable). The survival of wild fingerling brown trout for this same period was 24.1 per cent, but might be expected to be higher than that of the hatchery fish as the latter were stocked in riff and in the relatively unproductive flat water alike.

The numbers of wild legal-sized brown trout influenced the catch by anglers, for with 526 present in the 4.17 miles of stream in 1939, 0.275 fish were taken per hour as compared to catches of 0.192 fish per hour in 1940 when 424 were present, and 0.088 fish per hour in 1941 when 245 were present.

Of the number of 2-year-old brown trout (age-group II) present, 26.5 per cent were caught by anglers, as compared to 22.6 per cent of the number of 3-year-olds, 12.0 per cent of the 4-year-olds, and only 8.83 per cent of the 5-year-olds.

Throughout the stream there were an estimated 1,053 wild brown trout per mile of fast water as compared with only 481 per mile of slow water. Trout under 8.4 inches (total length) were more numerous in the fast water, and those 8.4 inches long or longer were more numerous in the slow water. On a per-mile basis there were on the average 421 fingerlings, 106 yearlings, 48.6 2-year-olds, 31.1 3-year-olds, 11.2 4-year-olds and 5.0 5-year-olds each year.

The average length of wild fingerlings in the fast-water areas (3.24 inches) was significantly greater than the average of 2.92 inches for those in the slow-water areas.

The lengths in inches in September for the various age groups were as follows: 0 group, 3.09; I group, 5.69; II group, 7.56; III group, 10.15; IV group, 11.65; V group, 14.02. The weights in grams for fish of these ages were 4.8, 27.0, 75.1, 182.9, 263.6, and 435.2, respectively.

Movement of the wild brown trout from September to September was surprisingly slight; most fish were found where originally tagged. Most ascended the stream in October and November but returned to their original locations.

INTRODUCTION

The stocking of streams with large numbers of hatchery trout has been depended upon for many years to provide satisfactory fishing. When fish-cultural practices were initiated it was believed that natu-

ral reproduction in the wild was extremely inefficient, and that artificial reproduction, rearing, and stocking were highly efficient and therefore certain to increase the quantity of catchable fish in natural trout waters by almost any degree desired.

Recently data have come to light which suggest that in some situations artificial stocking has been rather ineffective, and tremendously expensive in terms of the fishing actually produced. The survival of hatchery fish (White, 1924, 1927, 1930) and their returns to anglers (Shetter, 1939; Surber, 1940; Cobb, 1934; Nesbit and Kitson, 1937; Smith, 1941; Shetter and Hazzard, 1941; Hazzard and Shetter, 1939) have been found to be much less than would be expected from the survital tables of Embody (1927) and Davis (1938). These researches have by no means been conclusive, and much work obviously is needed to check upon the survival of hatchery-reared trout, but it appears probable that the ability of these fish to survive is considerably below the earlier estimates.

To evaluate correctly the quality of the hatchery-reared trout with respect to survival, it seems proper to compare their survival with that of wild trout. Information on the survival of wild trout appears to be absent from publications, and partly to obtain such information the New York State Conservation Department maintained a research project on Crystal Creek in northern New York, during the years 1939 to 1942.

Crystal Creek, like most streams in the Adirondack Mountains, was originally a brook trout (*Salvelinus fontinalis*) stream. It is at present primarily brown trout (*Salmo fario*) water. The section selected for study included a small pond and about 4.17 miles of stream directly above the pond. The stream had an average width of 24.3 feet, an average depth of 14.6 inches, a minimum flow of 10 to 15 cubic feet per second, and water velocities of 0.91 feet to 2.27 feet per second. The highest temperatures recorded were in the low 70's, and chemical characteristics of the water were satisfactory for maintaining trout. The stream flowed through fairly open pasture land, and was lined with alders along much of its length. The bottom in the slow water areas was predominantly sand, and in the fast sections was rubble, boulders, and sand.

The operations carried out in this 4-year period consisted of (1) a creel census, (2) maintenance of weir traps during the fall spawning season, (3) an annual population inventory of the 4.17 miles of stream, (4) many special studies of varied nature. The population inventories produced information on survival, population density, growth, and movement of the wild brown trout in this stream. This paper will be devoted to a discussion of certain of the findings from these annual inventories. Other aspects of these studies, and the complete work on the creel census and hatchery trout will be presented in later publications.

The population studies consisted of inventories of the wild brown

trout population in 13 sample sections of the 4.17 miles of stream at the close of each fishing season in 1939, 1940, 1941, and 1942. The trout in these sections were captured by use of an electrical shocking apparatus (Haskell, 1940; Haskell and Zilliox, 1941). Data obtained included the number of wild brown trout in each section, their lengths and weights, and samples of their scales. Age determinations were made from the scale samples, and the average total length and its variation for each age group were computed. Inasmuch as the electrical shocking method was not 100 per cent efficient in capturing the fish in any section, and since the efficiency was higher for larger than for smaller trout, the figures representing the numbers of each age group were corrected for the estimated efficiency of the electrical shocking method on the different sizes of fish. The theoretical numbers in the whole stream were then estimated from the findings in the 13 sections studied. Thus an estimate of the numbers of wild brown trout of various ages in each of 4 years was available, and consequently an estimate of the survival from year to year could be made. Other information on growth, length-weight relationship, density of the population of fish in slow- and fast-water areas, movement, etc., was also available.

In the following discussions, all lengths of trout are total lengths in centimeters. All weights are in grams and were obtained by weighing individual live trout in a previously balanced and covered gallon jar of water. All estimates of population are for the 4.17 miles of stream only, and unless otherwise specified, "trout" means wild brown trout only. Legal-sized trout are all those 7 inches (17.8 cm.) long, or over.

Survival

Methods employed.—The popualtion inventories were conducted during the first two weeks of September from 1939 through 1942. The same 13 sample sections, which comprised 2,788 feet, or about 12.7 per cent of the total stream length, were inventoried in each of the four years. Eight of these sample sections were of a "flat" or slow-water nature, and the remaining five were "riff" or fast-water sections. This distribution was roughly proportional to the total amount of riff and flat water in the stream. As already stated, the method of electrical shocking was used in capturing the fish in these 13 sections. Each section, prior to being inventoried, was segregated from the rest of the stream by nets placed across both extremities, and the electrical apparatus was operated back and forth from one end of the blocked-off section to the other until one trip was made in which no trout were taken.

Data obtained.—The data obtained for the individual fish taken in each of the 13 sections were: total length, weight (if 6 inches long or over), tag number if tagged, and scales from a portion of the fish. A study of the scales served to determine the ages of the trout of

various sizes. The average total length for each age group, its standard deviation, and the estimated range of length were then computed (Table 1). Since all scales were obtained in September, age-group 0 (fingerlings) would be about 5 months from hatching, or 10 months from egg deposition; age-group I (yearlings) would be about 17 months from hatching and 22 months from deposition. Age-group V includes the averages of all fish 5 years old and older, due to the fact that too few scale samples were available on fish older than five years to obtain accurate length data on these fish.

TABLE 1.—*Average length in centimeters, its standard deviation and the estimated range of length for each of the age groups of wild brown trout from Crystal Creek.*

Age group	Average length	Standard deviation	Estimated range
0	7.85	0.97	5.2 to 10.5
I	14.45	1.42	10.6 to 16.8
II	19.20	1.48	16.9 to 21.3
III	25.80	3.11	21.4 to 27.1
IV	29.60	5.35	27.2 to 32.0
V	35.65	5.61	32.1 to 41.2

From the estimated length ranges for the various age groups shown in Table 1, all of the brown trout in the 13 sections were classified in the appropriate age group according to their individual total lengths. These data for the four years are presented in Table 2.

Efficiency of the electrical shocking method.—It was known that the method of electric shocking did not catch all of the trout in any section, and it was further known that the relative efficiency or number caught in proportion to the number actually present, was different for different sized fish. The larger trout were captured more efficiently, possibly because they were more conspicuous after being stunned. It is obvious that any count of the relative numbers of the different sized trout in a section would be incorrect, unless an estimate of the relative numbers of trout that were missed was available for the purpose of correction. Fortunately such an estimate was available, as this subject had been investigated during the summer of 1941. In that investigation four areas of the stream were segregated by the construction of weirs with ¼-inch-mesh screens and the electrical apparatus was operated in the standard manner four times, at about weekly intervals, in each of the four areas. By marking all fish taken in the first inventories, and observing the proportion of marked to unmarked fish appearing in the later inventories, an estimate was available as to the relative efficiency of the method of capture. No difference was found in the relative rate of recovery between the two riff and the two flat-water sections, but there was a decided difference in the rate of recovery for fish of various sizes. The relationship between the size of the fish and the observed rate of recovery is shown in Figure 1. This relationship was used as the basis for estimating the total numbers of the different sizes of fish present in the 13 sections from the numbers actually taken.

To obtain the appropriate correction factor for the various age

TABLE 2.—*Actual numbers of wild brown trout of the various age groups taken in the 13 sections of Crystal Creek each year.*

Year	Age group	Riff sections					Flat sections								
		1	2	3	4	5	1	2	3	4	5	6	7	8	Total
1939	0	11	3	4	21	10	12	9	5	16	6	6	12	2	117
	I	0	4	15	9	14	4	3	4	3	0	0	1	0	57
	II	0	3	3	5	3	2	2	3	1	1	0	2	0	25
	III	0	2	1	0	2	1	6	2	3	1	0	2	2	22
	IV	1	0	0	0	0	1	1	3	1	1	0	2	0	10
	V	0	0	0	0	0	1	0	1	0	0	0	0	0	2
1940	0	14	3	7	11	14	13	8	11	17	2	2	3	12	117
	I	0	6	2	13	18	3	7	7	2	2	0	4	1	65
	II	1	4	3	7	10	0	5	5	2	0	0	4	1	42
	III	0	1	0	2	2	1	4	2	0	0	0	2	1	15
	IV	0	0	0	0	1	1	0	0	0	0	0	2	1	5
	V	0	0	0	0	0	1	0	0	3	1	0	0	0	5
1941	0	15	7	9	25	30	7	4	4	8	7	0	3	14	133
	I	0	1	6	4	6	0	4	6	3	0	1	2	1	34
	II	0	1	2	3	5	2	0	1	1	0	0	2	1	18
	III	0	0	0	2	0	4	3	1	1	0	0	0	0	11
	IV	0	0	0	0	0	0	0	0	0	1	0	2	0	3
	V	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1942	0	10	8	16	16	9	7	6	6	18	2	3	2	6	109
	I	0	4	4	8	4	2	7	8	5	0	0	1	3	46
	II	0	3	2	1	0	2	2	2	1	0	0	1	3	17
	III	0	0	0	1	3	1	4	0	1	0	0	1	1	12
	IV	0	0	0	0	0	0	0	0	2	0	0	1	0	3
	V	0	0	0	0	0	0	0	0	1	1	0	0	0	2

groups, into which all of the fish had previously been classified, the average total length of each age group, shown in Table 1, was entered in Figure 1, and an estimate of the relative rate of recovery for each age group was obtained. The rates of recovery for the various age groups were as follows:

Age-group 0	50 per cent
Age-group I	81 per cent
Age-group II	92 per cent
Age-groups III, IV, and V	95 per cent

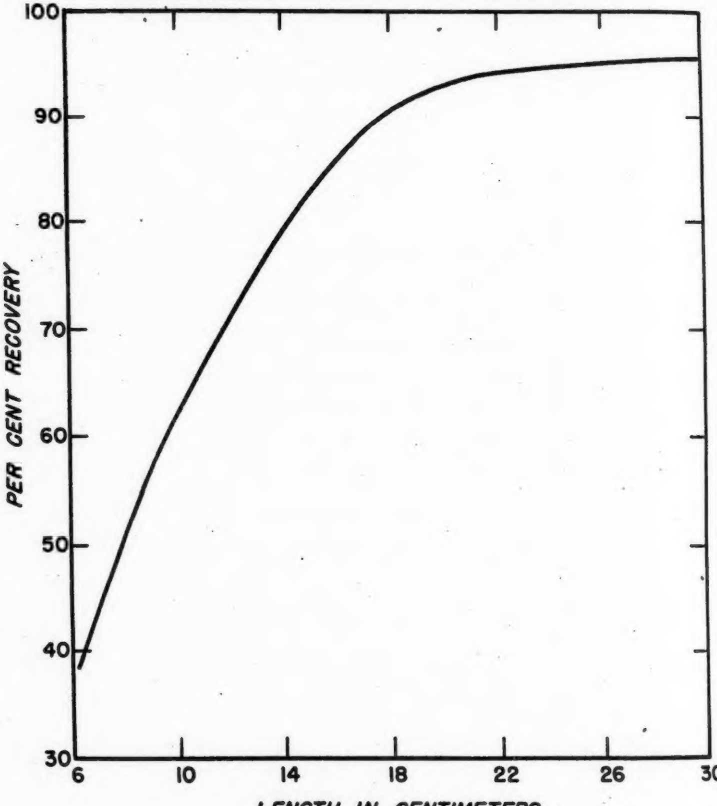

FIGURE 1.—Relationship between the total length of wild brown trout in centimeters and the recovery efficiency of the electrical shocking apparatus expressed in terms of the percentage recovery of trout of that size present in a section of stream.

TABLE 3.—*Numbers of wild brown trout of the various age groups taken in the 13 census sections of Crystal Creek each year, corrected for the efficiency of the electrical shocking method.*

Age group	Year	Riff sections					Flat sections								
		1	2	3	4	5	1	2	3	4	5	6	7	8	Total
0	1939	22	6	8	42	20	24	18	10	32	12	12	24	4	234
	1940	28	6	14	22	28	26	16	22	34	4	4	6	24	234
	1941	30	14	18	50	60	14	8	8	16	14	0	6	28	266
	1942	20	16	32	32	18	14	12	12	36	4	6	4	12	218
I	1939	0	5	18	11	17	5	4	5	4	0	0	1	0	70
	1940	0	7	2	16	22	4	9	9	2	2	0	5	1	79
	1941	0	1	7	6	7	0	6	7	4	0	1	2	1	42
	1942	0	5	5	10	5	2	9	10	6	0	0	1	4	57
II	1939	0	3	3	7	3	2	2	3	1	1	0	2	0	27
	1940	1	4	3	8	11	0	6	6	2	0	0	4	1	46
	1941	0	1	2	4	6	2	0	1	1	0	0	2	1	20
	1942	0	4	2	1	0	2	2	2	1	0	0	1	4	19
III	1939	0	2	1	0	2	1	7	2	3	1	0	2	2	23
	1940	0	1	0	2	2	1	5	2	0	0	0	2	1	16
	1941	0	0	0	2	0	5	3	1	1	0	0	0	0	12
	1942	0	0	0	1	3	1	5	0	1	0	0	1	1	13
IV	1939	1	0	0	0	0	1	1	4	1	1	0	2	0	11
	1940	0	0	0	0	1	1	0	0	0	0	0	2	1	5
	1941	0	0	0	0	0	0	0	0	0	1	0	2	0	3
	1942	0	0	0	0	0	0	0	0	2	0	0	1	0	3
V	1939	0	0	0	0	0	1	0	1	0	0	0	0	0	2
	1940	0	0	0	0	0	1	0	0	3	1	0	0	0	5
	1941	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1942	0	0	0	0	0	0	0	0	1	1	0	0	0	2

Computation of the number of trout in the stream.—The numbers of fish of the various age groups, shown in Table 2, were corrected on the basis of these relative rates of efficiency for the electrical method. The estimated total numbers in the 13 sections are shown in Table 3.

Inasmuch as the ratio of the length of the 13 sample sections to the total stream length was known, it was possible to estimate the population of the whole stream. Because the population was different in riff and flat water, the following method of computation was used in determining the population of the 4.17 miles of stream: The length of the eight flat-water sections totaled 1,897 feet and the length of all flat water in the 4.17 miles of stream was 16,670 feet. Thus the num- of fish of a certain age group in all eight flat-water sections was multiplied by 16,670/1,897, or 8.80. Likewise the length of the five riff sections totaled 893 feet and there were 5,330 feet of riff water in the 4.17 miles of stream. The number of a certain age group in the five riff sections was multiplied, therefore, by 5,330/893, or 5.97, to give the population of the riff water of the stream. The number of any age group in the whole stream was obviously the number in the riff water

TABLE 4.—*Total number of wild brown trout of each age group in the whole stream (Crystal Creek) in the four years.*

Year	Age group 0	I	II	III	IV	V	Total
1939	1,780	472	193	188	94	18	2,745
1940	1,780	563	328	127	41	44	2,883
1941	1,854	311	140	100	26	0	2,431
1942	1,586	431	148	103	26	18	2,312
Total	7,000	1,777	809	518	187	80	10,371

TABLE 5.—*Detailed estimates of the survival of the wild brown trout of different ages in Crystal Creek in the various years.*

Age interval (years)	Time interval	Decrease in numbers of trout	Percentage survival
0 to 1	1939 to 1940	1,780 to 563	31.7
	1940 to 1941	1,780 to 311	17.5
	1941 to 1942	1,854 to 431	23.0
	Total	5,414 to 1,305	24.1
1 to 2	1939 to 1940	472 to 328	69.5
	1940 to 1941	563 to 140	24.9
	1941 to 1942	311 to 148	47.7
	Total	1,346 to 616	45.7
2 to 3	1939 to 1940	193 to 127	65.7
	1940 to 1941	328 to 100	30.5
	1941 to 1942	140 to 103	73.6
	Total	661 to 330	49.9
3 to 4	1939 to 1940	188 to 41	21.8
	1940 to 1941	127 to 26	20.5
	1941 to 1942	100 to 26	26.0
	Total	415 to 93	22.4
4 to 5	1939 to 1940	94 to 44	46.8
	1940 to 1941	41 to 0	0.0
	1941 to 1942	26 to 18	69.3
	Total	161 to 62	38.5

plus the number in the flat water, as the stream had previously been divided arbitrarily into the two types of water. The estimated number of fish of each age group in each of the four years in the 4.17 miles of stream is shown in Table 4.

Survival rate under conditions of angling.—It can be seen that Table 4 provides the basis for an estimate of the survivals of the wild brown trout in Crystal Creek over this 4-year period. For example, the I-group fish in 1940 were survivors of the 0-group fish of 1939. Likewise, the IV-group individuals in 1942 had survived from I-group fish of 1939, the II-group of 1940 and the III group of 1941. The detailed estimates of the survivals are shown in Table 5. The average survivals of the various ages to the next year are seen in this table to be as follows:

Age group	*Percentage*
0 group to I	24.1
I group to II	45.7
II group to III	49.9
III group to IV	22.4
IV group to V	38.5

The survivals from the fingerling stage (age-group 0) to all older ages were computed from the above figures and were as follows:

Age group	*Percentage*
0 group to I	24.10
0 group to II	11.00
0 group to III	5.49
0 group to IV	1.25
0 group to V	0.48

The above survival data are presented graphically in Figure 2.

Survival rate with effect of angling removed.—Since angling was in progress during these 4 years, the survivals at least among the legal-sized wild brown trout were obviously affected by this circumstance. It was, however, possible to eliminate the effect of angling from the data on survival. A creel census was maintained during the years 1939, 1940, and 1941, during which seasons anglers removed 147, 65, and 45 legal-sized wild brown trout respectively. In 1939, 59 of these fish were 2-year-olds, 74 were 3-year-olds, 13 were 4-year-olds, and 1 was a 5-year-old fish. In 1940, there were 33 2-year-olds, 24 3-year-olds, 6 4-year-olds, and 2 5-year-olds. In 1941, 16 of those taken were 2-year-olds, 23 were 3-year-olds, 3 were 4-year-olds and 3 were 5-year-olds. A creel census was not conducted in 1942.

With this information, it was possible to add the number of fish taken by anglers to the numbers present in the different age groups at the close of the fishing season; these totals are shown in Table 6.

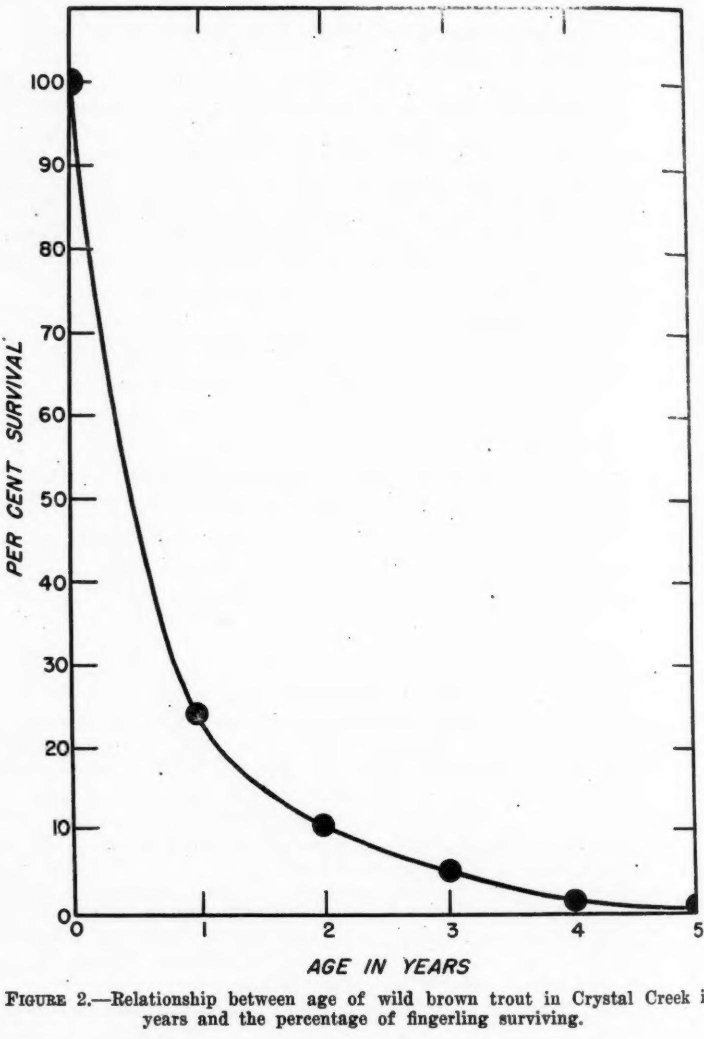

FIGURE 2.—Relationship between age of wild brown trout in Crystal Creek in years and the percentage of fingerling surviving.

From these values the survivals from year to year were recalculated and the results are summarized as follows:

Age group	*Percentage*
0 to I	24.10
0 to II	12.00
0 to III	5.38
0 to IV	0.99
0 to V	0.31

These figures show the survival rate under conditions with no removals by angling, and can be contrasted to the previously presented survival rate where angling was removing a portion of the legal-sized fish. The two survival rates show very little difference, however, and it would therefore appear that a relatively small part of the loss of the legal-sized fish was due to angling. This source of loss was found to be about 15 per cent of the total loss of legal-sized trout from one year to the next, leaving the remaining 85 per cent to be ascribed to unknown causes.

Observed mortality.—A hint as to the source of some of the remaining losses was given by the appearance of relatively large numbers of dead and dying fish during the month of July in each year that a crew was on the stream. Some of the dying fish were sluggish and could be caught easily in a scap net or with bare hands. Some appeared blind and made no effort to escape, often lying in shallow, sunny, and unprotected waters where they could be seen from some distance. The color of these fish was usually very dark, sometimes almost black. Such specimens were thin, and they invariably had empty stomachs.

TABLE 6.—*Number of wild brown trout estimated to be present in Crystal Creek at the beginning of the three fishing seasons.*

Year	Fingerlings	Yearlings	Age-group II	Age-group III	Age-group IV	Age-group V	All age groups
1939	1,780	472	252	262	107	19	2,892
1940	1,780	563	361	151	47	46	2,948
1941	1,854	311	156	123	29	3	2,476
Total	7,000	1,777	925	648	211	87	10,648

Others of the dead and dying were in good condition and color, and their stomachs contained food recently eaten. This food often consisted of large numbers of rose beetles (*Macrodactylus subspinosus*). Inasmuch as these beetles have been reported as toxic to chickens (Lutz, 1921) it was thought possible that they might have been a contributing cause of the mortality. They were very numerous over the stream during July of 1939 and 1940, but were absent in 1941, when a heavy mortality also occurred.

During the periods of heaviest losses water conditions appeared to be good. Chemical analyses revealed normal conditions with respect to oxygen, carbon dioxide, and pH. No evidences of pollution or of

deliberate poisoning were found, and only brown trout died; no brook trout, suckers, or minnows were found at this time. The flow of water was good, and temperatures were satisfactory (never rising above 72° F.).

Survival of hatchery-reared fingerlings.—There were many plantings of hatchery-reared trout in Crystal Creek during the period of study but the data regarding them will be treated in a forthcoming paper. One point of interest in regard to survival will be summarized here, however. Fingerlings (age-group 0) planted in September survived to the following September to an extent ranging from 0.25 per cent to 6.3 per cent, as determined by the method of annual inventory, already described. The figure of 6.3 per cent is considered more reliable, due to the greater precautions taken in marking and planting the fish from which these figures were obtained. It will be recalled that the survival of wild brown trout fingerlings over the same period of time was estimated to be 24.1 per cent. However, it should be noted that the survival of the wild trout must be expected to be greater than the hatchery fish, as they inhabited the more favorable riff sections, while the hatchery trout were stocked uniformly through the length of the stream in riff and flat water alike.

Population Density

The effect of the density of population of wild legal-sized brown trout upon the catch.—It was of interest to determine whether the number of legal-sized wild brown trout in the stream in indifferent years had any effect upon the number taken by anglers in these years. The numbers caught and the numbers available to anglers, *i.e.*, the numbers estimated to be present in September plus the numbers taken by anglers during the preceding season are presented in Table 7. It will

TABLE 7.—*Numbers of legal-sized wild brown trout present in Crystal Creek and the numbers caught by anglers in each of three years.*

	1939		1940		1941		Total	
Age group	Present	Catch	Present	Catch	Present	Catch	Present	Catch
II	138	59	180	33	90	16	408	108
III	262	74	151	24	123	23	536	121
IV	107	13	47	6	29	3	183	22
V	19	1	46	2	3	3	68	6
All ages	526	147	424	65	245	45	1,195	257

be seen that with a total of 526 present, 147 were caught; with 424 present, 65 were captured; and with 245 present, 45 were taken. These figures are not directly comparable, however, inasmuch as the number of fishing hours expended in the three years was different. The numbers of hours fished in the different years were: 1939, 536; 1940, 340; and 1941, 508. The more appropriate comparison is that between the

number of fish present and the catch per hour. This comparison for the three years is shown below:

Year	*Legal sized fish present*	*Number caught per hour*
1939	526	0.275
1940	424	0.192
1941	245	0.088

It thus appeared that the catch per hour steadily decreased as the number of legal-sized trout present in the stream decreased.

It can be seen from Table 7 that the percentages of the various age groups taken by anglers decreased with the age of the fish. Of the legal-sized fish of each age group available, 26.5 per cent of the 2-year-olds were caught, 22.6 per cent of the 3-year-olds, 12.0 per cent of the 4-year-olds and 8.83 per cent of the 5-year-olds. Whether a change of feeding habits occurred, or increased wariness developed as the fish grew older, is open to speculation.

Differences in population density between years and between age groups.—The numbers of trout showed no significant difference between the four years. With 2,745 fish present in the stream in 1939, 2,883 in 1940, 2,431 in 1941 and 2,312 in 1942, it can be seen that the numbers were relatively stable.

The numbers of trout varied widely according to age as was obvious from the previously presented (Table 4) totals of 7,000 fingerlings, 1,777 yearlings, 809 2-year-olds, 518 3-year-olds, 187 4-year-olds, and 80 5-year-olds in the whole stream in all four years.

Differences in density between riff and flat water.—Table 8 shows the numbers of wild brown trout of the various age groups per mile of riff and flat water. It can be seen from the totals that the number of fish was considerably greater in the riff than in the flat water and this difference was statistically significant. In the average year there were 1,053 trout per mile of riff water as compared to only 481 per mile of flat water. It can also be seen that fingerlings, yearlings, and 2-year-olds, or all fish less than 21.3 centimeters (8.4 inches) long, were more numerous in the riff water than in the flat water, and that 3-, 4-, and 5-year-old fish, or all those 21.4 centimeters long or larger, were more numerous in the flat water than in the riffs. This finding seems to bear out the observation of many anglers that the larger trout of most streams are generally found in the deeper and more slowly moving water, and that the smaller fish are generally in the faster and more shallow sections. The average depth of all riff sections was 1.04 feet as compared to 1.34 feet for the flat sections. Velocities in feet per second averaged 2.00 for the riffs and 1.20 for the flats.

Differences in population density among the 13 sections.—It was noted that certain of the 13 sample sections were consistently more productive of trout than were others, as can be seen from the totals in Table 3. The 4-year totals for the five riff sections were 102, 75, 115, 214 and 205, while the four-year totals for the eight flat water

TABLE 8.—*Numbers of wild brown trout per mile of riff and flat water in Crystal Creek*

Age group	1939		1940		1941		1942		Average	
	Riff	Flat	Riff	Flat	Riff	Flat	Riff	Flat	Riff	Flat
0	581.0	378.0	581.0	378.0	1,018.0	261.0	699.0	278.0	720.0	322.0
I	302.0	52.8	278.0	89.3	125.0	58.6	148.0	89.2	213.0	72.5
II	95.0	30.7	159.0	52.8	77.2	19.6	41.6	33.6	93.2	34.2
III	29.7	50.0	29.7	30.7	11.9	27.8	23.8	25.0	23.8	32.4
IV	5.9	27.8	5.9	11.1	0.0	8.2	0.0	8.2	3.0	13.8
V	0.0	5.7	0.0	13.9	0.0	0.0	0.0	5.7	0.0	6.3
Total	1,013.6	545.0	1,053.6	575.8	1,232.1	375.2	912.4	139.7	1,053.0	481.2

sections were 107, 113, 105, 151, 42, 23, 70 and 85. An analysis of variance (Snedecor, 1940) showed a significant difference in the numbers in the various sections in each year. The factors which contributed to such consistent differences were difficult to ascertain. It was thought that length of the section might be of some importance, but such was not the case. Other physical factors, such as width, average and maximum depth, and velocity of water had been recorded for each of the 13 sections, and correlations between these factors and the numbers of trout per section were computed, but most proved not to be significant. The correlation between the number of larger fish (age-groups III, IV, and V) and the volume and depth of water was found to be a significant one, however, as was the correlation between the number of fingerlings and the velocity and area of water in the sections. Greater numbers of the larger fish were present in areas of greater depth and volume of water, and greater numbers of fingerlings were present in sections with greater velocity and area.

Certain sections were even more favorable to one size of fish than the above correlations would suggest. For example, riff section No. 1 produced a total of 100 fingerlings in the four years and a total of only two fish in age-groups II, III, IV, and V. This section was relatively shallow, fast, and with no pools of any consequence. Its average depth was 0.89 feet as compared to the average of 1.25 feet for the other 12 sections, and its average velocity was 2.14 feet per second as compared with 1.46 feet per second for the other sections.

Numbers and weights per mile and acre.—A reduction of Table 4 gives the numbers of the various age groups per mile as follows: Fingerlings, 421; yearlings, 106; 2-year-olds, 48.6; 3-year-olds, 31.1; 4-year-olds, 11.2; 5-year-olds, 5.0. In all an average of about 622 wild brown trout per mile was present in Crystal Creek each year at the close of the fishing season.

The 4.17 miles of stream constituted about 12.3 acres of water. The population figures reduced to a per-acre basis are as follows:

Age group	*Number per acre*
0	142.0
I	36.1
II	16.4
III	10.5
IV	3.8
V	1.6
All ages	210.4

As to legal-sized trout, there was an average of 67.9 per mile or about 23 per acre at the close of the fishing season each year.

The estimated average weights of the various age groups at the close of the fishing season each year were:

Age group	*Pounds per mile*	*Pounds per acre*
0	2.72	0.92
I	6.29	2.13
II	8.02	2.72
III	12.53	4.25
IV	6.51	2.21
V	4.78	1.62
All ages	40.85	13.85

It can be seen that although the number of fish in the various age groups constantly diminished the total weight increased up to age group III and then decreased.

Growth

The average lengths for the various age groups were presented previously in Table 1. The corresponding weights in grams were as follows: fingerlings, 4.8; yearlings, 27.0; 2-year-olds, 75.1; 3-year-olds, 182.9; 4-year-olds, 263.8; 5-year-olds, 435.2. The relationship between age and length is presented in Figure 3, and the relationship between age and weight is shown in Figure 4. All of these values were from September measurements.

Size of fingerlings in riff and flat-water areas.—It has already been noted that more fingerlings were found in riff sections than in flat-water sections. During the inventories the impression was also gained that those found in the riffs were larger than those in the flat sections. In the four years a total of 471 wild brown trout fingerlings (young of the year) were measured—242 from the riff sections and 229 from the flat water. These measurements were analyzed by the t test (Snedecor, 1940) and a highly significant difference was found between the average lengths of the two groups of fish. The riff-water fish averaged 8.23 centimeters with a standard error of the mean of 0.0513, while the flat-water fish averaged only 7.42 centimeters with a standard error of 0.0450. A graphical picture of the length frequencies of the two groups is shown in Figure 5. Although the reasons for the difference are subject to speculation, the relative abundance of food in the riffs, as compared to the sandy-bottomed flat areas possibly is of great consequence.

Length-weight relationship.—Lengths and weights were obtained from several hundred wild, untagged brown trout from Crystal Creek. A graphical representation of the length-weight relationship for these fish is shown in Figure 6. It has already been demonstrated that these wild brown trout tagged for periods of 1 and 2 years were significantly lighter for their length than were the untagged trout in this stream (Schuck, 1942).

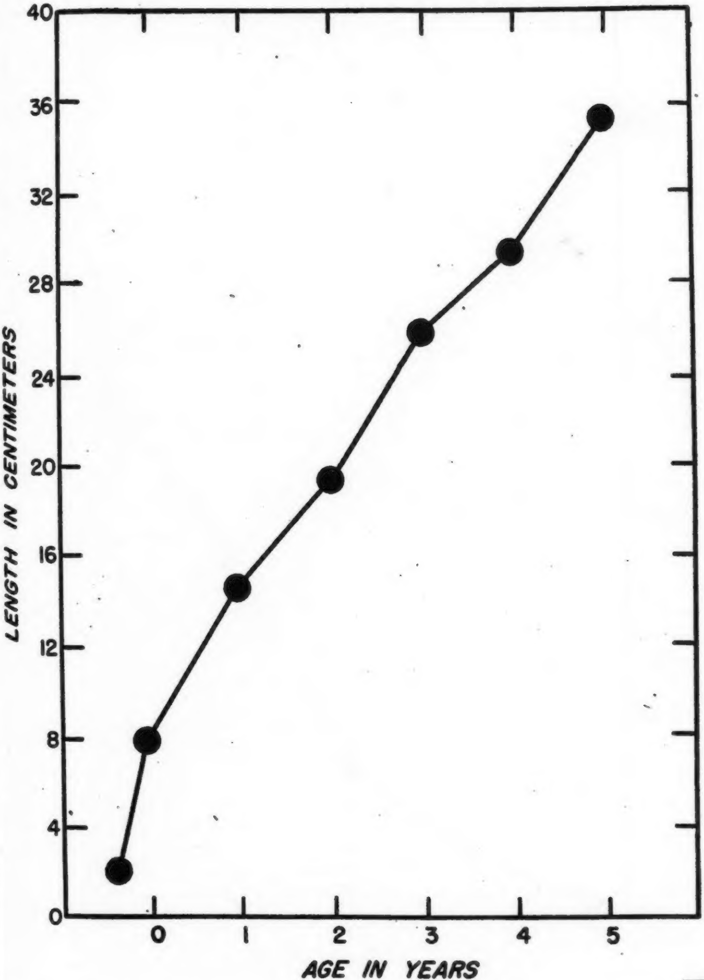

FIGURE 3.—Relationship between age in years and total length in centimeters of the wild brown trout in Crystal Creek.

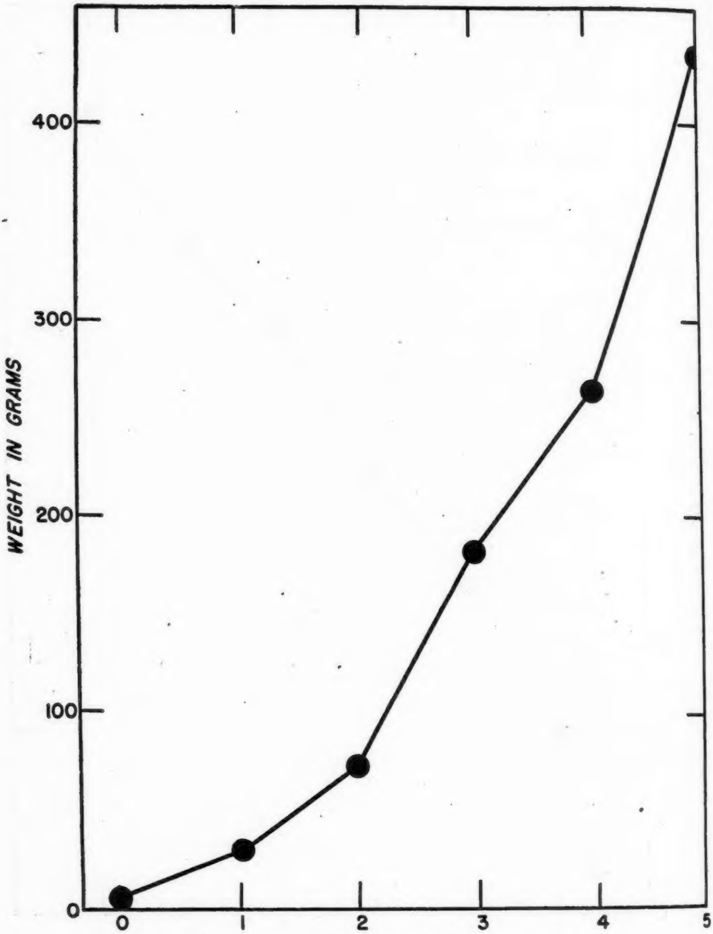

FIGURE 4.—Relationship between age in years and weight in grams of the wild brown trout in Crystal Creek.

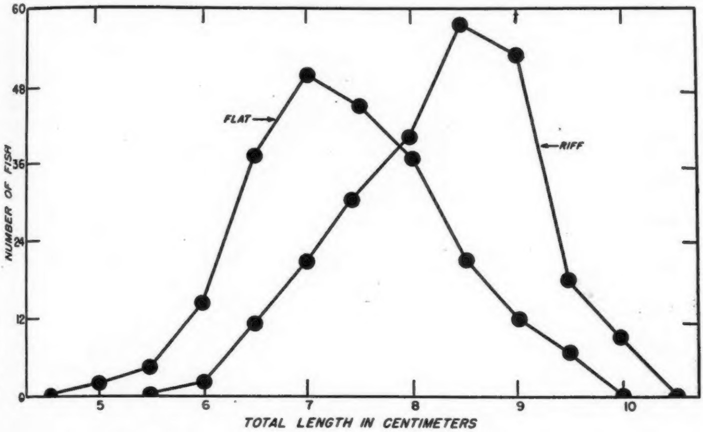

FIGURE 5.—Length-frequencies of wild fingerling brown trout from flat- and from riff-water sections of Crystal Creek.

The average condition factor (weight in grams times 100 divided by the cube of the standard length in centimeters), for all wild brown trout in this stream was about 1.44.

MOVEMENT

During the annual inventories of the 13 sections and of other special sections all wild brown trout 6 inches (15.2 centimeters) long or larger were tagged, and the section in which they were taken was recorded. Some of these fish were recaptured in the inventories of subsequent years (September), some were taken by anglers during the fishing seasons, and some were recaptured in weir traps maintained in the stream during October and November to check upon the spawning movement.

Movement from September to September.—Of 46 fish recovered in the annual September inventories after being tagged for a period of 1 year, 42 were taken in the identical individual sections in which they were tagged the previous September. This appears remarkable considering the fact that these sections had an average length of only 214 feet, and that a year had passed since tagging in those sections. The remaining four fish were taken from 400 to 1,300 feet from the point of tagging—two upstream and two downstream.

In addition, there were five fish that were taken in the identical inventory sections three years in succession.

Movement from September to the fishing season.—Of those fish

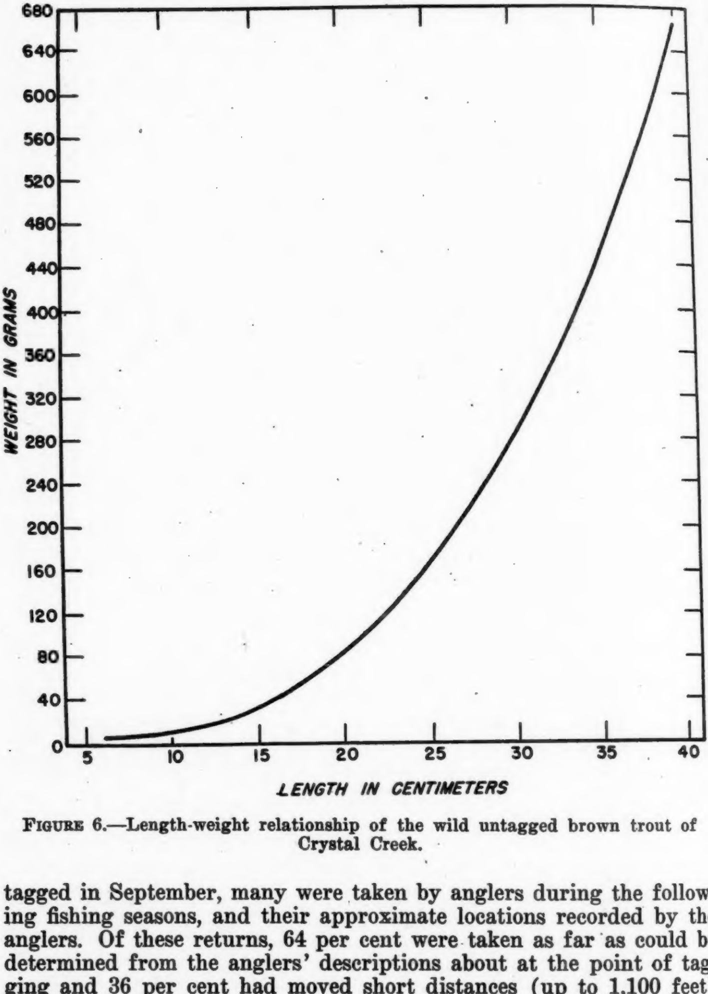

FIGURE 6.—Length-weight relationship of the wild untagged brown trout of Crystal Creek.

tagged in September, many were taken by anglers during the following fishing seasons, and their approximate locations recorded by the anglers. Of these returns, 64 per cent were taken as far as could be determined from the anglers' descriptions about at the point of tagging and 36 per cent had moved short distances (up to 1,100 feet) upstream or downstream. The numbers that moved upstream and downstream were approximately the same.

Movements from September to the spawning season.—A weir to check upon the spawning movement was operated during October and

November at a point about three-fourths of the way up the stream. Many of the fish tagged in the September inventories in sections lying below the weir were caught moving upstream during the period when the weir trap was in operation. The interesting fact was that these fish were later recovered the following September, most of them in the inventory sections from which they had ascended the previous autumn. These "home sites" were in some instances several miles below the location of the weir trap, and this fact seems to show the surprising extent to which these larger-sized trout tended to remain in the location of their initial preference, leaving it to spawn upstream, but returning sometime later, probably during the winter.

Acknowledgements

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WINTER FEEDING HABITS OF BLUEGILLS, *LEPOMIS MACROCHIRUS* RAFINESQUE, AND YELLOW PERCH, *PERCA FLAVESCENS* (MITCHILL), IN CEDAR LAKE, WASHTENAW COUNTY, MICHIGAN[1]

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ABSTRACT

During the winter of 1940-41, 1,128 bluegills and 211 yellow perch were collected from the rather productive Cedar Lake, Washtenaw County, Michigan. Analyses were made of the contents of the stomachs of these fish.

Bluegills consumed very little food during the winter. The average stomach contained 133 organisms of which 124 were plankton. The average volumetric content of these stomachs was 0.036 cubic centimeters. Foods consumed were predominantly aquatic insects (mayfly nymphs) in early winter; changed to plankton (Cladocera) in midwinter; and tended again toward aquatic insects as spring approached. There was some correlation noted between prolonged periods of warm weather and an increased rate of food consumption.

Yellow perch ate much more food than did bluegills during the winter. The average volume per stomach was 0.26 cubic centimeters. Young bluegills constituted the great bulk of the perch diet. They formed over 60 per cent of the total volume throughout the winter. Ostracoda were eaten in great numbers in midwinter.

Winter predation by perch on young bluegills certainly must be an important factor in regulating the bluegill population.

INTRODUCTION

The winter feeding habits of bluegills (*Lepomis macrochirus*) and yellow perch (*Perca flavescens*) are not very well known. The winter food of perch in Wisconsin lakes was described by Pearse and Achtenberg (1920), and Adams and Hankinson (1928) mentioned the winter feeding of perch in Oneida Lake, stating that in February of 1921, they were feeding solely on *Hexagenia* (mayfly nymphs). Hankinson also summarized much of the literature on bluegill and perch feeding in the same paper. No mention was made of any studies on winter feeding habits of bluegills. Because of the variations in the feeding habits of both species in different waters, no definite dietary list can be compiled. It is sufficient to state that both species are quite omnivorous, with the bluegill tending toward an insect-zooplankton fare with

[1]**Contribution from the Institute for Fisheries Research, Michigan Department of Conservation, and the U. S. Fish and Wildlife Service.**

some vegetation intermixed, and the perch utilizing about the same food but favoring a diet of fish as they grow larger.

In the following study, data are presented which were secured from Cedar Lake, Washtenaw County, Michigan, during the winter of 1940-41. Fish collections were made by the authors and by other staff members of the Institute for Fisheries Research. The junior author assisted materially in the laboratory sorting and in determining the volume of organisms recovered from the stomachs.

Methods

All fish examined during this study were taken by hook and line, allowed to freeze on the ice until each day's collecting was completed, and were then weighed, measured, and eviscerated. Scales were taken from some for age analysis. Each stomach was identified by a numbered label inserted in it. The same number was recorded opposite the length and weight of that fish from which the stomach was removed. This method was rapid and convenient and none of the inserted labels were lost or defaced by gastric juices. Organisms recovered from stomachs were counted and then measured volumetrically by water displacement. The bottom portion of a centrifuge tube graduated in tenths of a cubic centimeter was used to measure volume; graduations on this cone-shaped part were spaced sufficiently far apart to allow relatively accurate estimates to the nearest 0.025 cubic centimeter.

General Features of Cedar Lake

Cedar Lake has an area of 73 acres. Its regular basin is shallow in the east portion and slopes gradually on all sides to a simple depression 27 feet deep in the west third of the lake. Lake-bottom materials are predominantly pulpy peat but some marl and fibrous peat occur in the shoal areas. The lake's contributing drainage is small and the soil comprising it is of poor quality. No permanent inlet or outlet streams are present.

The lake water is colorless and quite clear. It stratifies thermally and chemically in summer and is highly alkaline. The pH range is between 7.4 and 8.6, and the total hardness expressed in terms of calcium carbonate is 112-130 parts per million.

Biologically, Cedar Lake is considered fairly productive. Many extensive weed beds on its shoals produce large quantities of invertebrate fish food and offer considerable shelter for young fish. Bottom-fauna samples taken from the plant zone March 1, 1941, contained many mayfly nymphs, Amphipods (*Hyalella*), and dragon and damselfly nymphs. Snails and fingernail clams (Sphaeriidae) were common in the same area. Midge larvae and aquatic earthworms were relatively abundant in the bottom ooze in this zone and to water depths of 12-16 feet. In the deepest portion of Cedar Lake very few bottom organisms were found despite repeated sampling. Most of the insects and snails

consumed by the fish were of the same kinds that inhabited the beds of recumbent vegetation in the shoal areas.

Winter fishing in Cedar Lake was exceptionally good during the 1940-41 season. Good catches were made on practically all collection dates with the best fishing between the hours of 4:00 and 6:00 p.m. The contributors to this study expended approximately 313 hours of fishing effort to catch 1,128 bluegills (including hybrids), 211 perch, 94 pumpkinseed sunfish, 52 black crappie, and 7 largemouth black bass or a total of 1,492 fish. The rate of capture was 4.77 per hour.

Growth rates of the fish considered in this work were studied but for the sake of brevity, details and tabulations are omitted. It is necessary to note only that bluegills grew slowly in Cedar Lake, reaching a total length of 6 inches (legal size) during their sixth year of life. The average annual length increment was 15 millimeters and the yearly weight increase was about 18 grams. It is quite evident that the bluegill population was stunted. Perch reached the same length during their fifth year of life and showed the same signs of stunting although not as markedly as did the bluegills.

Winter Conditions During the Study

The winter of 1940-41 was comparatively mild in Michigan, and Cedar Lake did not freeze over permanently until January 5-10, 1941. The ice cover became about 10 inches thick during the course of the winter. It was clear and of good quality early in the season but successive thaws and freezes covered the original layer with about 4 to 5 inches of clouded ice. Snowfall was light; a continuous cover was present only during the last half of February.

Feeding Habits of the Bluegill

During the winter of 1940-41, bluegills in Cedar Lake consumed a rather large variety of organisms although quantities taken were small. Fifty-four genera were identified in the food eaten and this number is minimal since several groups were identifiable to family only. In 1,128 stomachs examined (935 with contents, 193 empty) there was an average of 133 organisms of which 124 were plankton. The average volumetric content of these stomachs was 0.036 cubic centimeters including debris.

Cladocera (*Daphnia* and *Bosmina*) were the most numerous plankton organisms eaten during early winter (Table 1). They became subordinate to Ostracoda during midwinter and increased to a highly dominant position in late winter. Copepoda were eaten consistently but in relatively small numbers. Of the insect foods, mayfly nymphs belonging to the genus *Blasturus* were most abundant although *Ephemerella* nymphs were almost as numerous. Together these genera made the mayfly group more important than any other order of insects during all periods when insect foods were being eaten in appreciable

TABLE 1.—*The winter diet of bluegills from Cedar Lake, January 18 to March 18, 1941*
[Percentages of the total number of organisms recovered from stomachs. tr. denotes "trace."]

Item	January		February							March			Entire winter
	18-19	25-26	1-2	6	9	12	15-16	22-23	27	1-2	8-9	18	
Number of stomachs:													
With contents	41	56	85	46	60	40	101	183	17	146	126	34	935
Empty	24	20	27	14	14	9	18	21	1	17	17	11	193
Totals	65	76	112	60	74	49	119	204	18	163	143	45	1,128
Organisms:													
Bryozoa	....	3.0	0.9	....	0.1	....	tr.	0.1	....	0.3	0.1	0.1	0.2
Annelida	....	....	....	....	....	....	....	tr.	....	....	....	....	tr.
Mollusca	0.8	1.1	0.6	0.5	1.1	0.4	1.1	0.3	12.7	0.8	0.5	0.7	0.7
Cladocera	58.1	49.3	77.0	95.6	60.7	60.5	40.0	49.6	70.7	72.0	91.3	82.6	67.3
Copepoda	4.6	6.6	6.9	1.2	33.5	13.4	2.2	1.2	4.4	9.6	5.0	0.2	6.0
Ostracoda	4.9	0.3	4.0	0.6	1.7	21.6	48.1	46.3	....	7.9	tr.	0.1	19.9
Amphipoda	0.6	0.3	0.4	0.1	tr.	....	tr.	tr.	0.5	0.2	0.1	0.3	0.1
Hydracarina	0.1	0.1	tr.	tr.	tr.	tr.	tr.	tr.	2.1	0.1	0.2	13.1	0.1
Ephemeroptera	22.6	31.1	5.3	0.3	0.2	tr.	5.8	0.9	2.9	5.0	1.3	0.1	3.2
Odonata	0.2	0.3	0.3	....	tr.	tr.	tr.	....	0.1	0.1	tr.	1.1	tr.
Trichoptera	2.0	0.7	0.9	0.2	0.1	tr.	0.1	tr.	0.5	1.0	0.4	1.5	0.3
Chironomidae	4.0	2.5	2.2	0.7	1.0	0.6	1.9	0.8	4.0	2.7	0.7	0.2	1.3
Other Diptera	2.1	4.6	1.5	0.8	1.5	3.4	0.7	0.6	2.1	0.3	0.3	....	0.8
Fish	....	0.1	tr.	tr.	....	tr.	tr.	tr.	....	tr.	....	....	tr.
Total numbers	1,331	2,392	6,143	7,718	7,818	9,456	16,250	39,059	758	18,623	35,979	4,636	150,163
Av. no. per stomach	20.5	31.5	54.8	128.6	105.6	192.9	136.5	191.5	42.1	114.2	251.6	103.0	133.1

TABLE 2.—*The winter diet of bluegills from Cedar Lake January 18 to March 18, 1941*

[Percentages of the total volume (less debris) of organisms recovered from stomachs.]

Item	January		February							March			Entire
	18-19	25-26	1-2	6	9	12	15-16	22-23	27	1-2	8-9	18	winter
Number of stomachs:													
With contents	41	56	85	46	60	40	101	183	17	146	126	34	935
Empty	24	20	27	14	14	9	18	21	1	17	17	11	193
Totals	65	76	112	60	74	49	119	204	18	163	143	45	1,128
Organisms:													
Byrozoa	....	3.2	2.7	....	....	....	....	0.7	....	1.2	0.6	....	0.9
Annelida	....	....	....	....	....	....	....	2.6	....	....	....	....	0.3
Mollusca	10.1	3.9	8.5	7.2	20.4	4.3	14.4	27.2	60.0	5.7	7.9	3.1	10.0
Cladocera	4.4	1.9	10.6	39.9	27.3	10.9	9.0	24.2	7.2	6.5	35.8	6.2	16.3
Copepoda	0.3	....	1.3	....	27.3	4.3	....	....	....	1.5	1.3	....	1.6
Ostracoda	0.7	0.8	5.3	....	....	8.7	20.5	22.2	....	0.9	....	....	4.9
Hydracarina	....	....	....	....	....	....	....	....	....	....	0.6	....	0.1
Ephemeroptera	43.1	65.7	32.9	4.8	....	....	29.5	4.8	7.1	39.5	16.2	63.1	30.5
Odonata	6.4	8.7	7.9	....	2.3	....	....	....	4.3	10.6	6.0	9.2	6.1
Trichoptera	25.2	1.6	18.8	2.4	2.3	....	1.0	....	7.1	13.5	23.6	10.0	11.5
Chironomidae	9.8	3.1	9.3	4.8	13.6	10.9	9.2	9.4	14.3	11.1	6.7	2.3	8.1
Other Diptera	....	....	....	2.4	6.8	26.1	....	1.1	....	0.6	1.3	6.1	2.2
Fish	....	11.1	2.7	38.5	....	34.8	16.4	7.8	....	8.9	....	....	7.5
Volume[1] less debris	1.485	3.160	1.885	1.040	1.10	1.150	3.050	3.825	0.35	8.450	7.890	3.25	36.635
Volume of debris	0.480	0.275	0.040	....	0.10	0.125	0.075	0.050	....	1.525	1.175	0.15	3.995
Total volume	1.965	3.435	1.925	1.040	1.20	1.275	3.125	3.875	0.35	9.975	9.065	3.40	40.630
Volume per stomach	0.030	0.045	0.017	0.017	0.016	0.026	0.026	0.013	0.019	0.061	0.063	0.075	0.036

[1]Volume in cubic centimeters.

numbers. At other times, especially in midwinter, the dipterous larvae, *Chironomus* and *Chaoborus,* outnumbered them. Other insect components were relatively unimportant and became increasingly so as the winter progressed. The presence of Bryozoa in the winter diet of the Cedar Lake bluegills is interesting. Wilson (1920) found *Plumatella ploymorpha* in stomachs of bluegills taken from Lake Maxinkuckee in late autumn.

Volumetric comparisons of the various components of bluegill diets in winter are presented in Table 2. During the first 3 weeks of the winter, mayfly nymphs, caddisfly larvae, and dragonfly nymphs constituted over 50 per cent of the volume of the food in the stomachs. As winter progressed, plankton became increasingly important only to decrease to a relatively unimportant position by the time the ice began to yield to spring weather. At no time did planktonic forms constitute more than 54.6 per cent of the volume of the stomach contents. *Daphnia* were the predominant plankton group. Their volume was less than that of Ostracoda during one week in midwinter but they resumed their dominant position following that time. Mollusca were eaten with the plankton, and during February were as voluminous as that group, but in early and late winter their percentage in the total diet was quite low. Mayfly nymphs, chiefly *Blasturus,* were the dominant insect group. They were exceeded in volume by *Chironomus* larvae during 4 weeks in midwinter and by Trichoptera in the collection of March 8-9. Mayfly nymphs again became the most important group during the last week of the study when spring feeding, preparatory to spawning, is presumed to have begun. There was a decrease in the volume of insect life consumed, Diptera excepted, during midwinter and an increase as spring approached. However, this trend was accompanied by a general decrease in the average total volume per stomach during midwinter and an increase toward spring (Fig. 1).

The feeding habits of bluegills change very little with the size of the fish. Only when these fish approach a total length of 200 millimeters (7.9 inches) do they tend to leave plankton and turn to feeding on insects and fish. The percentage of total volume which each major group of food organisms constitutes in the diets of the various size groups is presented in Table 3.

The food consumed by bluegills in winter is very meager when compared with the volumes eaten at other seasons of the year. Such restricted feeding is believed to be a function of temperatures which control the activities of the food organisms as well as the metabolic rate of fishes. A comparison of the curve for the mean daily air temperature with that for the average volume per stomach taken at each collection date as shown in Figure 1, indicates a rough correlation between extended periods of warmer weather and the consumption of food. Usually, these warmer periods were acompanied by sunshine which, presumably, warmed bottom deposits and shoal water where most insect components of the bluegill diet were located. The rather large

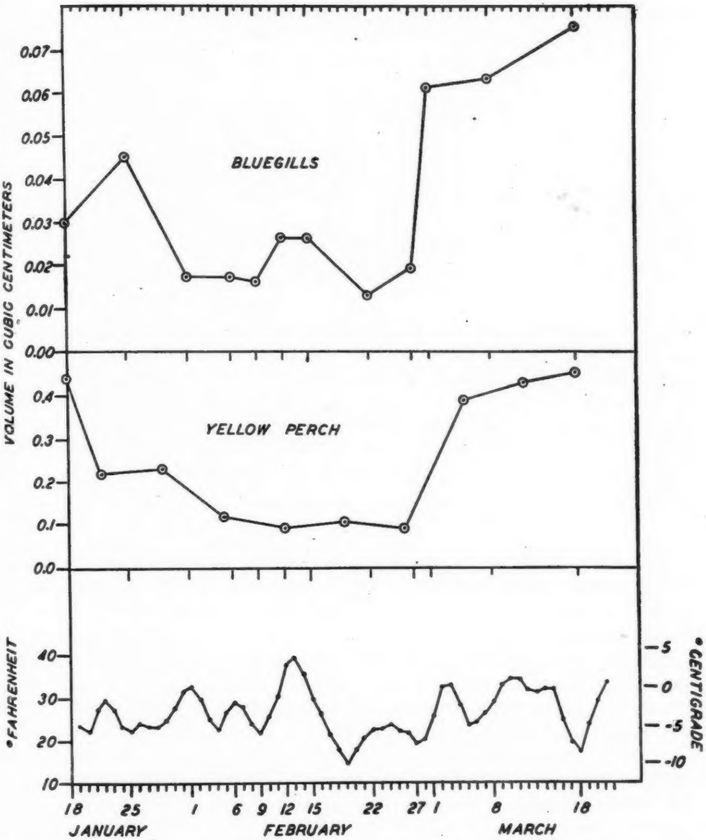

FIGURE 1.—The average volume of food contained in stomachs of bluegills and yellow perch taken from Cedar Lake during the winter of 1940-41. Mean daily air temperature $\left(\frac{\text{maximum} + \text{minimum}}{2}\right)$ is plotted for the same winter. The temperature curve has been smoothed by a three-point running average. The dates indicated along the base are the days on which collections were made.

TABLE 3.—*The winter diets of various-sized bluegills from Cedar Lake.*

[Percentages of number and volume.]

Size range in millimeters	Number of stomachs	Plankton Crustacea: Percentage of number	Plankton Crustacea: Percentage of volume	Insecta: Percentage of number	Insecta: Percentage of volume	Fish: Percentage of number	Fish: Percentage of volume	All others: Percentage of number	All others: Percentage of volume	Total number	Total volume
100-119	24	93.3	20.0	5.9	70.0	....	....	0.8	10.0	4,066	0.75
120-139	79	97.7	58.5	2.0	37.2	....	....	0.3	4.3	21,468	2.09
140-159	212	96.0	41.7	2.7	33.3	....	....	1.3	25.0	48,451	6.63
160-179	210	93.3	28.7	5.8	57.8	....	5.0	0.9	8.5	32,491	7.50
180-199	72	82.0	6.4	16.7	80.8	....	9.1	1.3	3.7	6,516	5.48
200-219	14	13.5	....	82.5	52.7	0.5	47.3	3.5	....	377	1.58

volume of mayfly nymphs taken from stomachs collected February 15-16 (Table 2), indicates a change in the feeding locale during this warm period. Slight temperature rises of this sort might be sufficient to increase the activity of food organisms and might also stimulate the movements of fish. Such action would tend to account for the correlation shown in Figure 1. This explanation is, of course, speculative since data resulting from this study are insufficient to prove it conclusively.

FEEDING HABITS OF YELLOW PERCH

The number of yellow perch stomachs involved in this work is not great enough to be considered by individual collection dates. Consequently, results of analyses as presented here have been grouped into weekly periods (Tables 4 and 5).

At the beginning of the period of ice cover, the yellow perch diet was dominated numerically by insects. Mayfly nymphs were most numerous during the first and second weeks. The mayfly group was the most prevalent component in the third week but was almost equalled by Ostracoda, the first plankton organisms to be eaten. During February and the first two weeks of March, plankton dominated the entire numerical picture. Ostracoda were by far the most abundant during mid-February. They were superseded by Copepoda in the last week of February and the first week in March, regaining their numerical dominance the second week in March. Only three yellow perch were collected during the third week in March, and their stomachs contained insects—chiefly mayfly nymphs—and fish.

The average number of organisms per stomach was naturally highest during the middle of the winter when plankton constituted the main diet of the perch. In contrast, the average volume per stomach was greatest during early and late winter, descending to a low level during the period when the numerical average was highest (Fig. 1).

TABLE 4.—*The winter diet of yellow perch from Cedar Lake January 18 to March 18, 1941*

[Percentages of the total number of organisms recovered from stomachs. tr. denotes "trace."]

Item	January[1]			February[2]				March			Entire winter
	12-18	19-25	26-1	2-8	9-15	16-22	23-1	2-8	9-15	16-22	
Numbers of stomachs:											
With contents	36	16	27	15	21	22	8	16	21	3	185
Empty	9	2	8	....	1	2	4	....	....	....	26
Totals	45	18	35	15	22	24	12	16	21	3	211
Organisms:											
Mollusca	....	....	....	....	tr.	....	....	....	....	....	tr.
Cladocera	....	....	....	1.8	0.3	12.8	6.5	....	....	....	3.5
Copepoda	....	....	0.4	45.8	15.4	5.4	73.2	76.0	8.8	....	17.4
Ostracoda	....	....	26.4	42.4	83.7	80.2	7.3	12.4	85.1	....	73.9
Amphipoda	....	1.5	1.2	0.6	tr.	tr.	....	0.6	0.4	....	0.1
Ephemeroptera	50.0	69.7	33.1	2.2	0.1	1.0	....	8.7	0.7	92.2	2.8
Odonata	0.7	1.5	6.3	1.6	tr.	tr.	....	0.3	0.5	....	0.2
Trichoptera	1.3	4.5	4.3	....	....	tr.	....	....	0.1	....	0.1
Chironomidae	10.3	9.6	15.0	1.2	0.3	0.1	8.9	0.6	2.1	3.9	0.8
Other Diptera	....	4.1	2.3	2.6	0.1	0.3	0.8	0.1	0.2	....	0.3
Bluegills	30.8	8.6	9.0	1.2	tr.	0.1	2.5	0.9	1.5	2.6	0.7
Lepomis(?)	0.7	....	1.2	0.2	....	tr.	....	....	....	....	tr.
Other fish	6.2	0.5	0.8	0.4	tr.	....	0.8	0.4	0.6	1.3	0.1
Total numbers	146	198	254	502	11,383	5,106	123	1,441	1,133	77	20,363
Average number per stomach	3.2	11.0	7.2	33.4	517.4	212.7	10.2	90.0	53.9	25.6	96.5

[1]Last period includes February 1.
[2]Last period includes March 1.

TABLE 5.—*The winter diet of yellow perch from Cedar Lake January 18 to March 18 1941*

[Percentages of the total volume (less debris) of organisms recovered from stomachs.]

Item	January[2]			February[3]				March			Entire
	12-18	19-25	26-1	2-8	9-15	16-22	23-1	2-8	9-15	16-22	winter
Number of stomachs:											
With contents	36	16	27	15	21	22	8	16	21	3	185
Empty	9	2	8	....	1	2	4	....	....	....	26
Totals	45	18	35	15	22	24	12	16	21	3	211
Organisms:											
Cladocera	....	....	....	....	....	1.1	....	....	....	....	....
Copepoda	....	....	....	....	3.5	....	....	0.8	....	....	0.2
Ostracoda	....	....	0.7	4.4	27.5	9.1	....	0.4	0.6	....	1.7
Ephemeroptera	1.3	4.6	2.7	....	1.4	2.3	....	7.1	0.3	11.1	2.5
Odonata	....	0.6	2.5	1.5	....	....	....	1.3	1.1	....	0.8
Trichoptera	0.2	0.6	1.1	....	....	....	....	....	....	....	0.3
Chironomidae	0.1	0.6	0.6	....	4.0	....	....	0.4	....	....	0.4
Other Diptera	....	....	....	1.5	1.4	....	....	....	....	....	0.1
Bluegills	89.7	91.6	87.9	67.6	62.2	86.4	91.3	75.8	74.1	81.5	83.5
Lepomis(?)	1.1	....	2.9	11.8	....	1.1	....	....	....	....	1.2
Unidentifiable fish	7.6	2.0	1.6	13.2	....	....	8.7	14.2	23.9	7.4	9.3
Volume[1]	18.240	3.875	7.850	1.700	1.850	2.200	1.150	6.000	8.700	1.350	52.915
Volume of debris	1.490	....	....	....	0.025	0.025	....	0.150	0.200	....	1.890
Total volume	19.730	3.875	7.850	1.700	1.875	2.225	1.150	6.150	8.900	1.350	54.805
Volume per stomach	0.438	0.215	0.224	0.113	0.085	0.101	0.085	0.384	0.424	0.450	0.260

[1]Volume in cubic centimeters.
[2]Last period includes February 1.
[3]Last period includes March 1

Fish constituted over 90 per cent of the volume of the winter diet during every week of this study except February 9-15 when they represented 62 per cent. Pearse and Achtenberg (1920) demonstrated a similar situation in several Wisconsin lakes during winter although their results were not quite so clear-cut. Cladocera, Chironomidae, and plants were quite abundant in the winter diet of the perch they examined. Most of the fish eaten by perch from Cedar Lake were small bluegills between 30 and 40 millimeters long. These bluegills were probably young of the previous spring's spawning. There were usually two and often three of them in each stomach containing fish.

When the results of stomach analyses of the perch from Cedar Lake are tabulated according to size groups with no regard for date of collection, there seem to be definite differences in feeding habits among the groups (Table 6). Perch less than 119 millimeters long fed almost entirely on invertebrates. In this particular study, plankton forms were most often eaten by these fish and constituted about 74 per cent

TABLE 6.—*The winter diet of various-sized yellow perch from Cedar Lake January 18 to March 18, 1941*

[Percentages of the total number and volume[1] of organisms recovered from stomachs.]

Size range in millimeters	Number of stomachs	Groups of organisms								Total number	Total volume
		Plankton Crustacea		Insecta		Fish		All others			
		Percentage of number	Percentage of volume	Percentage of number	Percentage of volume	Percentage of number	Percentage of volume	Percentage of number	Percentage of volume		
100-119	50	99.0	73.8	1.0	21.4	....	4.8	....	....	15,420	1.05
120-139	17	95.7	10.3	3.8	22.0	0.3	67.7	0.2	....	3,312	1.70
140-159	15	....	....	12.0	....	88.0	100.0	....	....	25	8.48
160-179	14	....	....	85.9	7.5	11.4	92.5	2.7	....	149	5.03
180-199	6	26.9	....	3.9	....	69.2	100.0	....	....	26	5.60
200-219	6	....	....	....	....	100.0	100.0	....	....	14	4.60
220-239	4	....	....	....	....	100.0	100.0	....	....	13	3.90

[1]Volume expressed in cubic centimeters.

of the total volume. The next larger sized perch (120-139 millimeters, total length) ate many invertebrate organisms although, volumetrically, fish made up 67 per cent of their diet. Perch in size groups above the two just discussed tended more and more toward a diet of fish. Mayfly and dragonfly nymphs were eaten occasionally but fish, especially bluegills, were practically the sole dietary constituent.

The average volume of the stomach contents of perch was much greater than that of the bluegills at all times during the winter. The predominance of fish in the perch diet is probably responsible for this difference. Considered by weeks, a curve showing the average volume of the stomach contents of perch follows the same general trend as noted for the bluegills (Fig. 1), but fluctuations in volume of food eaten at various times during the winter are not so marked. There

was a slight increase in average volume per stomach immediately following the prolonged warm temperatures of mid-February.

Heavy utilization of young bluegills as winter food by the perch in Cedar Lake must have a marked effect in reducing the bluegill population. It cannot be said that such predation is a typical annual occurrence, but even though it were usually less, its influence would be an important controlling factor in the abundance of bluegills.

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FACTORS INFLUENCING PRODUCTION OF YELLOW PIKE-PERCH, *STIZOSTEDION VITREUM VITREUM*, IN MINNESOTA REARING PONDS

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ABSTRACT

Stomach analyses of 947 yellow pikeperch fingerlings taken from rearing ponds show that fry begin feeding on rotifers and nauplii, and that as the fish increase in size Entomostraca, insects, and fish successively become important items in the diet. Yield and management data from 185 ponds suggest that the best means of controlling cannibalism and increasing yields are: (1) fertilization to promote an early and sustained crustacean crop; (2) use of forage fish as a food and "buffer population"; and (3) harvesting at a weight of 50 to 80 fingerlings to the pound. The average yield per acre of yellow pikeperch from ponds in Minnesota for the period 1940-1943 was 48.4 pounds and 2,111 fingerlings; this output was lower than that of other game-fish ponds. The average yields in pounds per acre attained in yellow pikeperch ponds under different management methods were: neither forage nor fertilizer, 7.5; fertilizer only, 41.6; sucker fry but no fertilizer, 44.0; and minnows but no fertilizer, 95.8. Few ponds succeeded that had a game-fish or minnow population when fry were stocked. Data from 10 experimental ponds demonstrate that fertilization is usually necessary to produce an early crustacean crop and that the most effective types of fertilizer are commercial fertilizer and sheep manure. Cottonseed meal and superphosphate were found to be relatively ineffective. Water analyses on 10 experimental ponds and 71 rearing ponds suggest that a greater utilization of the natural fertility can be had in most ponds through more intensive management.

INTRODUCTION

The yellow pikeperch or walleye, *Stizostedion vitreum vitreum* (Mitchill), is heavily utilized in Minnesota's sport and commercial fisheries. In an effort to maintain production, various catch restrictions have been imposed and artificially propagated fry have been planted since about 1887. Because fry stocking was found to be ineffective in many waters, an extensive program of fingerling production was initiated during 1940. Lack of information on suitable procedures and extreme variations in yields made a careful study of the factors involved in pond-rearing of yellow pikeperch desirable. The present observations have been limited to the food and growth of fingerling pikeperch and the factors influencing the production of 176 state-operated ponds. Experiments on the survival of planted fish

and methods of pond management and fertilization are now in progress. Although many important phases of the general problem are still undeveloped, the results presented here outline some essential considerations.

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FOOD AND GROWTH OF FINGERLING YELLOW PIKEPERCH

Food habits.—Since successful fertilization and use of forage must be based on knowledge of food requirements, 947 stomachs of pond-reared yellow pikeperch were examined. The standard length of the fish ranged from 6.5 to 214 millimeters (Table 1) and the age from 10 to 223 days. Specimens were collected in bobbinet and one-quarter-inch-mesh minnow seines. All samples were killed and preserved in 10-per-cent formalin immediately after capture. Since volume measurement or estimation of the different foods taken by small fishes is difficult and inaccurate, no attempt has been made to evaluate food consumption on this basis. Instead, the numbers of fish taking food and the average number of organisms found in each fish were used as an index of food consumption (Table 1). The invertebrate organisms were identified usually to genus but occasionally only to larger groups. Fish remains were identified to species when possible. The fish-food data were tabulated by size groups because age was shown to have little relation with the food selection.

Of the 947 fish examined, 818 contained food, and of the total number containing food 13.3 per cent had eaten fish, 38.2 per cent copepods, 40.1 per cent cladocerans, 60.6 per cent insects, 1.8 per cent rotifers, 1.1 per cent nauplii, and 1.1 per cent miscellaneous items. Table 1 shows that the predominantly crustacean diet of the small fish was increasingly augmented by insects and fish as the fingerlings grew larger. At no stage of development was algal or other plant food taken in appreciable quantities.

Rotifers constituted an important item of diet for fish between 5 and 9 millimeters long but none were found in specimens larger than 14 millimeters. The forms occurring were *Keratella cochlearis, Brachionus* spp., *Asplanchna* sp., *Euchlanis* sp., and *Synchaeta* sp. A dinoflagellate, *Ceratium hirundinella,* was frequently taken from stomachs that contained rotifers.

Copepods were taken in quantity until the fish reached the length of 60 millemeters. As the size of the fish increased, the number of copepods declined and none were found in fish over 120 millimeters.

TABLE 1.—*The food of small yellow pikeperch taken from rearing ponds as shown by stomach analysis*

Size range (millimeters)	Number of fish with food	Rotifera		Copepoda		Cladocera		Insecta		Fish		Miscellaneous	
		Percentage of fish feeding	Average number of organisms per fish	Percentage of fish feeding	Average number of organisms per fish	Percentage of fish feeding	Average number of organisms per fish	Percentage of fish feeding	Average number of organisms per fish	Percentage of fish feeding	Average number of organisms per fish	Percentage of fish feeding	Average number of organisms per fish
5-9	21	66.6	5.2	23.8	4.8	28.5	4.8	0.9	1.0	0	0	4.7	5.0
10-14	58	1.7	3.0	98.2	9.0	56.8	4.5	51.7	1.7	0	0	0	0
15-19	64	0	0	65.6	17.6	53.1	6.8	50.0	3.9	4.7	2.3	0	0
20-24	68	0	0	67.6	13.4	82.3	25.7	80.8	4.9	0	0	1.4	1.0
25-29	38	0	0	47.3	10.3	36.8	18.9	50.0	3.8	15.7	4.8	0	0
30-34	24	0	0	58.3	9.1	58.3	17.5	70.8	3.0	4.1	1.0	0	0
35-39	19	0	0	63.1	55.7	63.1	44.6	47.3	2.3	5.2	15.7	0	0
40-44	23	0	0	56.5	137.2	78.2	64.1	60.8	3.6	4.3	1.0	0	0
45-49	49	0	0	42.8	30.5	44.8	104.7	63.3	9.8	8.1	1.0	0	0
50-59	61	0	0	34.4	7.6	60.7	143.7	63.9	11.2	3.3	1.0	1.6	1.0
60-69	43	0	0	16.2	3.4	32.5	84.1	79.1	17.3	11.6	1.0	2.3	1.0
70-79	56	0	0	21.4	17.4	19.6	48.7	62.5	14.8	17.8	1.6	12.5	5.1
80-99	118	0	0	17.7	10.8	23.7	161.2	69.4	15.7	17.7	1.5	7.6	3.1
100-119	98	0	0	15.3	0.7	18.3	90.3	71.4	19.4	15.3	1.3	13.3	8.2
120-139	36	0	0	8.3	0	22.2	186.0	50.0	30.0	41.7	1.1	13.8	11.2
140-159	21	0	0	9.5	0	14.2	4.0	28.6	37.6	71.4	1.1	23.8	12.2
160-179	14	0	0	21.4	0	0	0	14.3	57.5	50.0	1.3	7.1	2.0
180-214	7	0	0	14.2	0	0	0	42.8	95.0	4.2	0.6	0	0
Totals	818	1.8	5.1	38.2	18.9	40.1	64.1	60.6	12.7	13.3	1.5	1.1	6.7

Cyclops and *Diaptomus* together with their nauplii were the only forms recorded. *Cyclops* appeared most frequently in the stomachs of the smaller fish and *Diaptomus* became more numerous as the size of fingerlings increased. This selection is probably influenced by varying availability at different seasons although Leach (1927) suggested that *Diaptomus* is unpalatable to fry.

Several species of Cladocera were taken by yellow pikeperch from the time they started to feed until they reached a size of 160 millimeters. The relative abundance of different species varied with the size of the fish. Fish less than 20 millimeters long fed largely upon *Chydorus* and *Bosmina*, while specimens longer than 20 millimeters took *Daphnia pulex* and *Simocephalus* sp. (principally *S. serrulatus*) in greatest numbers. *Daphnia pulex* was taken in quantities by fish as large as 120 to 129 millimeters. During the middle of the summer *Ceriodaphnia reticulata* entered conspicuously into the diet. *Alona* sp. was taken on one occasion. It is apparent from present results and those found in literature that the number and type of Cladocera taken are largely dependent upon their availability with the exception of *Chydorus* and *Bosmina*. These two genera, because of their small size, are eaten principally by the small fish and ignored as soon as the fingerlings are capable of ingesting larger material. In one experimental pond which had quantities of *Bosmina* throughout the season, the fish neglected them almost entirely after reaching a length of 25 millimeters.

Insect larvae are one of the staples of yellow pikeperch diet. Immature forms of Diptera, particularly chironomid and *Chaoborus* larvae, predominated. Ephemeroptera nymphs of several species were also taken in quantity especially from fish longer than 80 millimeters. Chironominae larvae were taken by pikeperch as small as 5 to 9 millimeters and continued to be eaten until the fish reached a length of 160 millimeters. Coleoptera, Hemiptera, Zygoptera, Anisoptera, and Trichoptera were also utilized in some quantities.

Fishes of any species available occasionally entered into the diet of yellow pikeperch as small as 15 to 19 millimeters, but they did not become important until the pikeperch reached an average length of 60 to 80 millimeters. Forage fish appeared to be used in proportion to their abundance. Pikeperch, although eaten consistently by their fellows, were taken in lesser numbers than forage species.

Various other organisms were eaten when opportunity permitted. Oligochaete worms, leeches, mollusks, algae, and higher plant remains were occasionally present but did not form an important proportion of the total food. Other workers have shown that a wide variety of food is taken by young pikeperch. For the most part they agree that the yellow pikeperch is generally carnivorous and that toward the middle of the first season of growth fish enters the diet in quantities.

Pearse (1921) found that five pikeperch taken from a Wisconsin lake on July 25 and ranging from 48 to 53 millimeters in length had eaten 52 per cent *Daphnia*, 3 per cent *Cyclops*, 0.4 per cent *Leptodora*, 13 per cent chironomid larvae, 30 per cent fish, and 2 per cent unknown material. Clemens *et al.* (1923), working in Lake Nipigon, collected three fish, ranging from 53 to 68 millimeters long, which had eaten only fish. Clemens *et al.* (1924), working in the same lake, found four fish between 35 and 94 millimeters long in which crustaceans were the most important food item. They further pointed out that specimens below 40 millimeters ate crustaceans exclusively. Insects were first observed in fish 45 millimeters long while Ephemeroptera were found in all size groups. Kidd (1927) reported that Entomostraca were the principal food of yellow pikeperch over the size range, 1.5 to 9 inches. *Gammarus* and small fishes were taken from specimens above 2 inches in length and various algae occurred occasionally in her samples. Six of eight fish, 1 to 2 inches long, collected by Adams and Hankinson (1928) had eaten only fish and the other two were empty. Rimsky-Korsakoff (1930) showed that 32 fish between 47 and 70 millimeters long had fed exclusively on perch and johnny darters. Sibley and Rimsky-Korsakoff (1931) took six fish between 55 and 95 millimeters long which had eaten only *Boleosoma nigrum*. Ewers (1933) examined 87 yellow pikeperch ranging in length from 24 to 190 millimeters taken from the west end of Lake Erie and found that 9.9 per cent of the estimated volume of food was Copepoda, 50.7 per cent Cladocera, 4.7 per cent Insecta, and 27.3 per cent fish. Of the fish taking the various foods, 24.1 per cent ate Copepoda, 64.3 per cent Cladocera, 8.0 per cent Insecta, and 28.7 per cent fish. Raney and Lachner (1942) examined 495 pikeperch from Oneida Lake. The mean standard length of these fish varied from 40.6 millimeters in the July 2 collection to 114.1 millimeters in the October 24 collection. Of the total estimated volume of food in the pikeperch examined, 92.9 per cent was fish, 3.7 per cent Insecta, and 2.7 per cent Crustacea. The crustaceans dropped out of the diet on July 19 when the fish had attained an average length of 55.7 millimeters. It was noted that the consumption of insects increased markedly in September.

Rate of growth.—The growth rate of yellow pikeperch in 63 ponds varied greatly according to the fertility, available fish forage and the management methods employed. Most of the data were collected at the time of harvest except from the seven experimental ponds which were sampled at regular intervals. Since ponds were usually harvested when fingerlings reached a desirable size, the slowly growing fish were generally left in the water for the longest period. In ponds where average growth was slow, two size groups developed when the fish were 40 to 70 days old. The larger fish grew rapidly and the discrepancy became more marked as the season progressed. In one

pond the size ranged from 98 to 169 millimeters after 150 days. At 160 days the average size in different ponds varied from 73 to 140 millimeters. The fastest recorded growth was 161 millimeters in 112 days.

To arrive at an approximation of the average growth rate, samples were collected periodically from the experimental ponds (Table 2). It wll be noted that between 20 and 100 days the length of the fish increased steadily. Ordinarily, growth was slow after 100 days. At 100 days the average size of 117.2 millimeters for pond fish was slightly greater than the average calculated growth for the first year in Minnesota lakes (Eddy and Carlander, 1942). It is smaller, however, than the calculated first-year growth in Lake of the Woods (Carlander, 1944) and in some other large Minnesota lakes. The averages shown in Table 2 are probably below those which can be obtained by the application of more intensive management methods since they do not include ponds where fastest growth rates occurred.

Pond Rearing of Pikeperch Fingerlings

History.—Although pond rearing of centrarchid and trout fingerlings has long been a standard hatchery practice, it is only in recent years that attempts have been made to rear pikeperch. Mannfeld, in the discussion appended to the paper of Cobb (1923), cited the use of a pond in Indiana for rearing this species. Twenty to thirty thousand fry stocked in a pond free from other fish produced 1,325 fingerlings whose length varied from 5 to 17.25 inches. The first extensive program of rearing pikeperch fingerlings was begun by the Iowa Department of Conservation in 1927. Speaker (1940) gave data on the stocking and yield for Center Lake which has an area of 250 acres and Diamond Lake with an area of 150 acres. The 2 years of data for Center Lake and 7 years of data for Diamond Lake showed that stockings of 13,300 to 100,000 fry per acre produced an average annual yield of 1,650 fingerlings per acre and a survival of fry to fingerling size of 4.3 per cent. Both lakes contained a large natural population of fathead minnows, green sunfish, orange-spotted sunfish, and bullheads.

In 1940, pond rearing of pikeperch fingerlings was begun in Minnesota; this program was expanded in 1941, 1942, and 1943. Total production of fingerlings during the first 4 years was: 47,350 in 1940; 130,772 in 1941; 671,155 in 1942; and 1,800,000 in 1943. The 185 ponds used during these years, with the exception of less than a dozen drainable hatchery ponds, were landlocked and ranged from 0.1 acre to 75 acres in area with a median of 8 acres. Most of the ponds have been operated for a single season. The data on 98 of these ponds are sufficiently complete to warrant analysis, but additional ponds are

TABLE 2.—*The average length in millimeters of yellow pikeperch in rearing ponds at successive intervals between 7 and 100 days*

Pond	Days of growth										
	7	10	13	16	20	30	40	50	60	80	90	100
Hatchery Pond No. 3	....	12.6	16.3	17.5	18.7	29.6	38.8	41.2	45.3	....	....	....
Hatchery Pond No. 4	....	10.6	11.7	13.6	13.7	20.8	22.7	57.2	64.2	....	....	....
Hatchery Pond No. 5	9.4	....	9.0	13.2	17.3	30.6	90.0	....	93.0	....	....	....
Dayton Pond	....	....	....	....	....	....	22.8	45.9	64.7	....	105.7	116.0
Larson Pond	....	....	....	....	....	26.0	....	47.6	59.4	87.2	106.9	116.6
Slade Pond	....	....	....	....	19.3	29.2	39.5	50.6	60.1	....	....	118.9
Mille Lacs	....	....	....	....	....	25.9	39.1	46.2	47.8	....	....	....
Average length	9.4	11.6	12.3	14.8	17.3	27.0	41.8	48.1	62.1	87.2	106.3	117.2

TABLE 3.—*Comparative yields of some yellow pikeperch, largemouth black bass, black crappie, and bluegill ponds in Minnesota for 1940, 1941, 1942, 1943*[1]

Species	Number of ponds	Yield (pounds per acre)			Number of ponds	Yield (numbers per acre)		
		Mean	Median	Range		Mean	Median	Range
Yellow pikeperch	64	48.4	29.3	3.0-234.0	66	2,111	1,043	21-8,790
Largemouth black bass	40	80.5	51.4	5.0-290.0	39	7,415	3,244	10-56,700
Bluegill	26	112.3	82.1	8.0-380.0	31	33,383	15,233	1,250-140,000
Black crappie	22	141.2	130.0	17.1-480.0	28	18,939	10,311	300-81,600

[1]Only ponds producing fingerlings 100 or more days old when harvested are included.

considered in the discussion of certain aspects of the rearing program.

Most of the ponds were stocked in May, usually about the middle of the month, and a few in late April and early June. The number of newly hatched fry planted ranged from 2,000 to 800,000 per acre with an average of 44,000 per acre. Ponds were seined 55 to 223 days after stocking, with an average of 128 days elapsing between planting and harvest. The usual length of the fingerlings at harvest was 70 to 100 millimeters (3 to 4 inches) and the weight was approximately 40 to the pound.

A number of ponds were stocked with forage fishes. In 45 ponds sucker fry were planted in numbers varying from 6,000 to 300,000 per acre, with an average of 37,000 per acre. Twelve ponds were supplied with minnows—mostly bluntnose and fathead minnows. A few were supplied with adult suckers, redhorse, and bluegills that had not yet spawned, and a few were stocked with eyed sucker eggs. About half the ponds considered were fertilized with sheep, barnyard, or horse manure in amounts usually between 200 and 400 pounds per acre. Usually fertilizer was applied in the early spring or placed on the ice during the winter.

Yield of yellow pikeperch ponds in Minnesota.—The harvest from 66 producing ponds ranged from 8.8 to 234 pounds of fingerlings per acre with a mean production of 48.4 pounds per acre. The median production of 29.3 pounds per acre is probably a more representative figure since the mean is influenced by a few extremely high yields. The mean number of fingerlings harvested after 100 or more days of growth was 2,111 per acre with a median of 1,043 per acre and the average survival from fry to fingerling size was 6.0 per cent.

Yellow pikeperch gave lighter yields than did black bass, black crappies, and sunfish reared in Minnesota ponds (Table 3). Production figures for the various species may be compared since, in general, the fish were all reared under comparable conditions. The only appreciable difference in methods was that many of the black bass ponds were drainable and on the average were more heavily fertilized than ponds containing other species. In each pond only a single game species was reared.

The average production in pounds per acre for yellow pikeperch ponds during the 4-year period, 1940-1943, was 34.3 per cent of that of black crappie ponds, 43.1 per cent of that of bluegill ponds, and 60.1 per cent of that of largemouth black bass ponds.

TABLE 4.—*The production of yellow pikeperch in unfertilized ponds with and without forage fish expressed in pounds and numbers per acre*[1]

Forage	Number of ponds	Yield (pounds per acre) Mean	Yield (pounds per acre) Range	Yield (numbers per acre)[2] Mean	Yield (numbers per acre)[2] Range
None	31	7.5	0- 89.0	301	0-5,344
Sucker fry	17	44.0	2.3-174.0	1,602	33-3,600
Minnows[3]	5	95.8	2.0-176.0	4,454	58-8,790

[1]Ponds with good production and ponds yielding no fish without apparent reason or yielding only a few fish are included.

[2]Only fingerlings 100 days or more old are considered.

[3]Most ponds were stocked with 10,000 minnows per acre.

Factors Influencing Pond Production

Cannibalism.—It was observed by Stranahan (U. S. Commission of Fish and Fisheries, 1900), and it is common knowledge among hatcherymen, that pikeperch fry begin to eat each other soon after hatching. To reduce cannibalism, fry are usually planted when they are less than a week old. Cannibalism in ponds results in a rapid decline of the fry population and an uneven growth rate of the survivors. Uneven growth was noted by both Mannfeld (Cobb, 1923) and Speaker (1940) and was evident in many Minnesota ponds. Many cases of low percentage survival, coupled with the production of a few pounds per acre of large fish, can probably be attributed to cannibalism since the fingerlings feed more frequently on fish as they increase in size. Experience with Minnesota ponds suggests that the two best means of controlling cannibalism and increasing yield are heavy fertilization and introduction of non-predaceous forage fish.

Forage fish.—Yellow pikeperch ponds that were stocked with forage fish had a yield markedly higher than ponds without forage fish (Table 4). The production of ponds in which white sucker fry were stocked at about the same time as the pikeperch fry was about six times that of ponds without forage. Ponds stocked with bluntnose and fathead minnows several weeks after the stocking of the pikeperch fry produced more than 12 times the poundage of the ponds without forage and more than twice the poundage of the ponds in which suckers were used.

Since yellow pikeperch and sucker fry were usually supplied in about the same numbers, it is evident that the suckers made up only a small part of the food consumed by the pikeperch throughout the season. Stomach analyses show that small pikeperch feed only occasionally on fish (Table 1). Since it is probable that the suckers provided a large proportion of these occasional meals, the number of pikeperch fingerling eaten by their fellows was reduced. The higher yield from ponds supplied with suckers as forage can probably be attributed in a large degree to this "buffer" effect. It should be noted that since the sucker population in pikeperch ponds decreases throughout the summer, its food and buffer value progressively declines. In contrast, bluntnose and fathead minnows tend to maintain themselves through natural reproduction and thereby provide a more constant buffering effect and a greater amount of food. These conditions are reflected in the higher yields of ponds supplied with minnows.

It is essential that minnows be added to the pond several weeks after the yellow pikeperch fry have been stocked. Many plantings in waters already containing minnow populations have failed, and the average yield for 13 ponds stocked in this way was only 5.5 pounds per acre. Sucker fry should be hatched and stocked later than the pikeperch fry since suckers are of greatest value when they are smaller than the pikeperch. In a few ponds suckers of the same age grew more rapidly

than did pikeperch and as a result were present in considerable numbers at the end of the season.

Fertilizer.—Of 55 ponds that were managed without forage, 24 were fertilized and 31 not fertilized. Those fertilized were supplied with sheep and barnyard manures applied to the ice in winter or scattered over the water in early spring. The amounts used ranged from 55 to 4,000 pounds per acre with an average amount of about 300 pounds per acre. In most ponds the need for fertilization was judged by a general examination of crustacean and insect crops and past records of yield. Analyses of water samples taken at the time of fingerling harvest (Table 5) demonstrated that most of the fertilized ponds had a lower basic fertility than those not fertilized. The average yield of 31 ponds supplied with neither fertilizer nor forage was 7.5 pounds and 304 fingerlings per acre. Twenty-four ponds, to which fertilizer was applied but no forage fish were added, produced an average of 41.6 pounds and 2,784 fish per acre, a yield about six times that of unfertilized ponds. The largest crops produced under these two methods of management were 89 pounds and 5,344 fingerlings per acre in a pond without fertilizer and 234 pounds and 1,000 fingerlings per acre in a fertilized pond.

Eight ponds in which a combination of sucker fry and fertilizer was used produced an average yield of 18.9 pounds and 3,618 fingerlings per acre, and four ponds in which both fertilizer and minnows were added had an average yield of 87.3 pounds and 9,129 fingerlings per acre.

On the basis of the data at hand, the most effective management appears to be fertilization to increase the crustacean crop, followed by planting of pikeperch fry and stocking bluntnose or fathead minnows several weeks after fry planting. Conversely, the least effective management is the stocking of pikeperch fry in ponds supplied with neither forage nor fertilizer. Most of the ponds that failed without apparent reason or produced a few large fish or fish with a wide range of sizes were managed in this way.

In an attempt to ascertain the best means of promoting an early crustacean crop and of sustaining this crop during the first weeks of growth of the yellow pikeperch, experimental fertilization was carried out on 10 ponds in 1942 and 1943. Seven were natural ponds whose size ranged from 2 to 5 acres and three were hatchery ponds of about one-fourth acre. One of the natural ponds and two of the hatchery ponds were operated as controls and the remainder fertilized with dried sheep manure, superphosphate, 10-8-6 commercial fertilizer, cottonseed meal, or combinations of these fertilizers (Table 6).[1] Fertilizer was added to the natural ponds at the rate of 300 pounds per

[1]The analyses of these fertilizers as percentages are: Sheep manure—nitrogen 2.0, phosphoric acid 1.0, potash 2.0; cottonseed meal—protein not less than 41.0, nitrogen-free ext act not less than 25.0; superphosphate—20.0; Armour's special turf fertilizer—nitrogen 10.0, available phosphoric acid 8.0, soluble potash 6.0. Combinations used were cottonseed meal and superphosphate, 3 to 1, and cottonseed meal and commercial fertilizer, 1 to 1.

acre in May and June. Four applications were made, the first 10 days before stocking, the second at the time of stocking, and the last two at 20-day intervals. Pond No. 5 at the St. Paul Hatchery was fertilized in 1943 at the same intervals but at a rate of 175 pounds per acre per application. Water samples were taken at 10-day intervals from all the ponds and analyzed for nitrogenous compounds, phosphorus, sulphates, total alkalinity, dissolved oxygen, and pH. Net-plankton samples were taken at 10-day intervals from the natural ponds and at 3-day intervals from the hatchery ponds. The sample usually represented 50 or 100 liters of water.

TABLE 5.—*Residual nitrogen and phosphorus in fertilized and unfertilized yellow pikeperch ponds at time of harvest*

Treatment	Number of ponds	Total phosphorus (p.p.m.)			Total nitrogen (p.p.m.)		
		Range	Median	Mean	Range	Median	Mean
Fertilized	38	0.005-0.185	0.052	0.061	0.200-1.744	0.478	0.612
Unfertilized	33	0.007-0.496	0.092	0.153	0.200-3.190	0.820	0.967

All ponds had good populations of rotifers in May and all, except South Palm and the three hatchery ponds, produced a blue-green algal bloom at some time during the season. However, the bloom in ponds fertilized with cottonseed meal or combinations of cottonseed and superphosphate did not have an associated heavy production of crustacea. Since the stomach analyses show that microcrustacea are the principal food of young yellow pikeperch (Table 1), the production of crustaceans has been taken as a good index of the value of fertilizers.

Commercial fertilizer (10-8-6) in Hilltop pond promoted the heaviest crustacean population and produced an early and sustained crop of *Daphnia* (Table 6). The average nitrogen content of this pond during May and June was 3.30 p.p.m. and the average phosphorous content 0.595 p.p.m., a ratio of 5.5 to 1 as opposed to a ratio of about 3 to 1 in the fertilizer. The nitrogen-phosphorus ratio in this pond was similar to those found by Swingle and Smith (1939) to produce the heaviest plankton crops in Alabama ponds. An average ratio of nitrogen to phosphorus of 2.39 to 0.409 p.p.m.[2] was found by Surber and Olson (1937) to produce a good *Daphnia* crop in Hyde Lake, a Minnesota largemouth black bass pond. In previous years, fingerling yellow pikeperch had shown good growth in this lake. Although yearling largemouth bass grew well all season in Hilltop pond, the dissolved-oxygen content was at times as low as 3.0 p.p.m. This fact suggests that the recorded chemical fertility and plankton production are near the safe maximum. The second best production of crustaceans was obtained with sheep manure in Larson pond. However, part of the chemical fertility and plankton production shown by this pond is probably due to occasional drainage from a nearby barnyard. The

[2]Analyses recalculated to make them comparable to others cited.

TABLE 6.—*Effects of fertilization on water fertility during May and June and production of microcrustacea in 10 experimental ponds, chemical concentrations recorded as parts per million*

Pond	Fertilizer[1]	Total nitrogen[2]		Total phosphorus[2]		Period of heaviest[3] crustacea production	Average number per 100 L[4] May and June	Principal genera
		Range	Mean	Range	Mean			
S. Palm	None	0.377-0.706	0.525	0.040-0.080	0.058	....	21	*Diaptomus*
St. Paul No. 3	None	0.240-0.430	0.381	0.050-0.100	0.062	June 3-27	3,691	*Bosmina*
St. Paul No. 4	None	0.175-0.408	0.254	0.045-0.060	0.058	June 15-24	511	*Bosmina*
St. Paul No. 5	Cm., Comm.	0.215-0.320	0.269	0.060-0.100	0.075	June 15	456	*Diaptomus*
N. Palm	Cm., Sp.	0.417-1.900	0.913	0.050-0.193	0.086	....	14	*Diaptomus*
Slade	Sp.	0.400-0.796	0.551	0.128-1.110	0.816	June 10-Aug. 21	511	*Cyclops*
Dayton	Cm., Sp.	0.220-0.690	0.475	0.053-1.100	0.321	June 18-Aug. 29	526	*Diaptomus*[5]
Larson	Sm.	0.778-1.420	0.980	0.128-1.110	0.719	May 21-July 10	5,535	*Diaptomus, Daphnia*
Bertiaume	Cm.	0.540-2.129	1.140	0.080-0.480	0.228	May 20-June 20	885	*Daphnia*
Hilltop	Comm.	1.060-5.560	3.300	0.210-0.707	0.595	May 9-June 20	7,588	*Daphnia*[5]

[1]Cm—cottonseed meal; Comm.—10-8-6 commercial fertilizer; Sm—sheep manure; Sp—superphosphate.
[2]First water samples taken just preceding the second fertilizer application.
[3]More than 1,000 crustacea per 100 liters.
[4]Average number of crustacea for all May and June samples, exclusive of Nauplii.
[5]Hilltop and Dayton also produced *Chaoborus* crops averaging 168 and 79 per 100 liters respectively for May and June.

crustacean production from a combination of cottonseed meal and superphosphate in Dayton and North Palm ponds was low, and that shown by Bertiaume pond was probably the result of the natural fertility rather than the effect of the fertilizers. Bertiaume pond produced 174 pounds of pikeperch per acre in the preceding year with suckers as forage but without fertilization of any kind. The data from the St. Paul Hatchery Pond No. 5 are of no comparative value since the pond leaked badly all summer and its level was maintained only by a constant supply of spring water. It will be noted from the water analyses that most of the fertilizer escaped as fast as it was applied. The difference in the production of crustaceans in the two unfertilized hatchery Ponds No. 3 and No. 4 can probably be attributed to the greater residual fertility of Pond No. 3 which was used as a trout pond the preceding year and supplied with trout food during that period. Superphosphate, alone, as judged from the crustacean production of Slade's pond, is insufficient. Cottonseed meal, while ineffective for crustacean production, did produce heavy crops of fathead minnows in two ponds. As suggested by Hogan (1933), the minnow production was probably more the result of direct feeding than of fertilization.

Natural fertility.—Minnesota lakes and streams include nearly the entire range of carbonate concentrations found in fresh waters as well as the lower end of the sulphate or alkali water series that is most typically developed in more western and arid regions. The concentration of dissolved solids in Minnesota waters shows a general but irregular increase from northeast to southwest and, with a few exceptions, ranges from 50 to 600 parts per million. Calcium is the predominant metallic ion, followed in descending order by magnesium, sodium, potassium, aluminum, and iron. Nitrogen and phosphorus concentrations have considerable range and seasonal variation in Minnesota waters and are usually highest in the waters of high carbonate and sulphate content.[3]

In an effort to ascertain the effect of these varied chemical conditions upon yellow pikeperch, water analyses were made on 66 ponds in the fall of 1942. Most of the samples were collected in August and September and analyzed within a few days of collection. The waters were analyzed for total alkalinity, expressed as calcium carbonate, and sulphate ion to determine the general chemical character of the water, and for total nitrogen and total phosphorus to determine the basic fertility.[4] Since most Minnesota waters have a potassium content

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[3]Data on dissolved solids, carbonates, sulphates, nitrogen, and phosphorus are largely from analyses by the Bureau of Fisheries Research, Minnesota Department of Conservation; analyses for metallic ions are from Dole and Wesbrook (1907) and Allison (1932).

[4]Total alkalinity and nitrogen were determined by procedures outlined in Standard Methods of Water Analyses (American Public Health Association, 1936). Total nitrogen was obtained by adding the totals of analyses for nitrite, nitrate, ammonia, and organic nitrogen. Total phosphorus was determined by the modified Denige method of Taylor (1937) and sulphate ion when in low concentrations by comparative turbidity in 50 cc. Nessler tubes using 1 cc. of saturated $BaCl_2$ solution and 2 drops of concentrated HCl as reagents and when in high concentrations by the titration method of Sheen and Kahler (1936).

greater than 2 parts per million and a calcium carbonate content greater than 12 parts per million, the amounts found by Swingle and Smith (1939) to be the minimum concentrations for high plankton production, it is probable that these substances are less important in determining fertility than are nitrogen and phosphorus.

Water analyses from the 66 yellow pikeperch ponds, summarized in Table 7, show that the ponds used in 1942 were representative of nearly the entire range of chemical conditions present in Minnesota surface waters. A comparison of the phosphorus and nitrogen analyses of pond waters with those of some important Minnesota yellow pikeperch lakes (Table 8) shows that, in general, the ponds exhibited a higher concentration of these substances than did the lakes. In a

TABLE 7.—*Summary of water analyses of 66 Minnesota yellow pikeperch rearing ponds*

Item	Total alkalinity (p.p.m.)	Sulphate ion (p.p.m.)	Total phosphorus (p.p.m.)	Total nitrogen (p.p.m.)
Range	7.5-290.0	0.0-490.0	0.003-.496	0.150-3.19
Median	91.9	0.5	0.062	0.492
Mean	127.7	32.1	0.110	0.721

few ponds this higher fertility may be a reflection of artificial fertilization applied during the previous spring. A comparison of concentrations of soluble and total phosphorus and the various nitrogenous compounds with analyses from fish-producing waters in other areas (Domgalla *et al.*, 1925; Pearsall, 1930; Juday and Birge, 1931; Yoshimura, 1932; Deevey and Bishop, 1941) shows that lake and pond waters of Minnesota have a high natural chemical fertility.

Water analyses from eight ponds producing more than 32.2 pounds per acre of fingerlings, the median production figure, indicate that in these ponds the total alkalinity ranged from 12.5 to 295.0 p.p.m. and the sulphate-ion content ranged from 0.0 to 192.0 p.p.m. Within this range it appears that the concentration of carbonates and sulphates has little effect on the production of yellow pikeperch. The tolerance of these fish to sulphate salts is known to be higher than the range just given, as Peterson Lake in Grant County with a sulphate-ion concentration of 490.0 p.p.m. produced 4.1 pounds per acre. A total alkalinity of about 15.0 p.p.m. is the lowest concentration of carbonates found in Minnesota lakes producing pikeperch. Lakes of this type, such as Alton Lake, Cook County, contain this species but do not provide consistently good fishing. Pikeperch are successful in Minnesota lakes having a total alkalinity approaching 200 parts per million.

No general correlation between the chemical content of the water and yield is evident in the data from the 66 ponds on which analyses were made. In the eight ponds having the highest yields, the total phosphorus ranged from 0.04 to 0.11 p.p.m. and the total nitrogen from 0.370 to 0.951 p.p.m. Compared to the entire series of ponds, these ponds were of moderate fertility. Similar inconclusive results

TABLE 8.—*Water analyses of some typical Minnesota yellow pikeperch lakes*

Lake	Date	Total alkalinity (p.p.m.)	Sulphate ion (p.p.m.)	Total phosphorus (p.p.m.)	Total nitrogen (p.p.m.)
Vermilion Lake	9-20-43	22.5	0.5	0.048	0.323
Lake of the Woods	9-13-43	41.3	0.0	0.058	0.258
Mille Lacs Lake....	10-8-43	97.5	0.4	0.038	0.709
Whitefish Lake	9-6-42	120.0	0.0	0.030	0.210
Leech Lake	7-8-43	155.0	5.0	0.060	0.188

were presented by Surber and Olson (1937) who worked on largemouth black bass ponds of Minnesota.

The lack of correlation between water chemistry and yield and the marked difference in yields shown by yellow pikeperch, black crappies, and bluegills in similar ponds (Table 3) suggests that the pikeperch utilize only a fraction of the available fertility and that more intensive management is required. It is noteworthy that best correlation between yield and fertility due to fertilization or the nature of the bottom soil has been obtained when bluegills, carp or other non-predaceous species were reared and cannibalism was not an important factor (Viosca, 1937; Smith and Swingle, 1940).

Data from the experimental ponds (Table 6) show that often the basic fertility is not converted into a crustacean crop early enough in the spring to be available when most needed by the small yellow pikeperch. A comparison of the residual nitrogen and phosphorous in fertilized and unfertilized ponds (Table 5) suggests that the main effect of manure in most ponds was to increase the crustacean crop when most needed rather than to increase perceptibly the general chemical fertility. A greater utilization of the natural fertility may be obtained by the use of forage fish, especially minnows. These fish, although feeding largely in direct competition with the small pikeperch during the first weeks, are able to utilize many of the small animals and plants not commonly taken by the pikeperch fingerlings later in the season.

Fingerling size and yield.—A comparison of the average number of fingerlings per pound when harvested with the yields in pounds and numbers per acre of the 62 ponds that produced them (Table 9) shows that the highest yield in pounds per acre was obtained when the fingerlings were harvested at a weight of 50 to 79 to the pound. At this weight the fingerlings are usually 3 to 3.5 inches (76 to 89 millimeters) long. It has previously been observed (Table 1) that at this size the predominantly crustacean and insect diet is increasingly supplemented by fish.

The number of fingerlings produced per acre was, for the most part, inversely proportional to the weight of the fingerlings. Although the production of large numbers of fingerlings is more important than poundage in rearing ponds, any increase in numbers of smaller fish must be balanced against the greater difficulty of handling and the probably lower survival rate.

TABLE 9.—***Relation of number of yellow pikeperch per pound to average yield per acre in Minnesota ponds***

Item	Number of fingerlings per pound				
	7-29	30-49	50-79	80-199	200-500
Number of ponds..	25	17	6	7	7
Pounds per acre....	33.5	46.7	87.2	48.1	38.5
Numbers per acre..	500	1,662	5,342	4,329	[1]11,069

[1]The highest yield in numbers per acre was obtained from Mille Lacs pond in 1943. This pond, which was fertilized with sheep manure and stocked with minnows, produced 24,587 fingerlings per acre that averaged 266 to the pound.

Pond size.—At the beginning of the pond rearing program it was assumed, because yellow pikeperch are most common in large lakes, that pond size might be a factor in production. For this reason larger ponds were used for pikeperch than were used for pan fishes. Data from the ponds operated in the period 1940-1943 indicate no correlation between size of pond and yield and that any pond of one-fourth acre or larger will produce pikeperch if crustaceans and fish are provided as forage in sufficient amounts and at the right times.

Predation.—Residual populations of yearling and adult yellow pikeperch, northern pike, largemouth black bass, yellow perch, and black crappies have caused many of the Minnesota pikeperch ponds to fail. Results from experimental ponds in 1942 suggest that as few as 50 yearling pikeperch or largemouth bass per acre will destroy or greatly curtail the fingerling crop. The influence of bullheads and mud puppies is not so well defined but several pond failures have been associated with large populations of each of these species. The opinion of Speaker (1939) that bullheads are a limiting factor in pond production of yellow pikeperch is borne out by observations of Minnesota hatcherymen who have found pikeperch fingerlings in the stomachs of adult bullheads taken from ponds. However, fair production has been had from some ponds with a large bullhead population. Although hatcherymen have attributed the failure of a number of ponds to mud puppies (*Necturus maculosus*), no pikeperch have been found in the stomachs of a small series of mud puppies taken from pikeperch ponds. However, Lagler and Goellner (1941) found that fish made up a small portion of the diet of mud puppies in a Michigan lake.

Several invertebrates prey on small yellow pikeperch fingerlings. In two ponds, near-failure was associated with heavy populations of leeches, and leeches were found attached to many of the fish. Larvae of predaceous diving beetles (Dytiscidae) have been observed to kill small pikeperch. When fingerlings are closely confined, as in live boxes, large numbers may be stung and killed by backswimmers (*Notonecta*).

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THE RELATIONSHIP BETWEEN THE PRODUCTION OF FISH AND THE CARBON AND NITROGEN CONTENTS OF FERTILIZED FISH PONDS

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Abstract

In ponds treated with a limited amount of fertilizer to produce optimum survival, the production of fingerling largemouth black bass, *Huro salmoides*, (Lacépède) has been increased by the addition of lime and/or colloidal phosphate to cottonseed meal fertilizer, with the greatest production where lime and colloidal phosphate were used together.

An inverse relationship existed between the loss of humus on the pond bottom and the production of fish. This fact suggests the use of the loss of humus as an index of the efficiency of the fertilizer. Similarly a positive correlation existed between fish production and the C/N ratio of the pond bottom taken shortly after the final application of fertilizer.

Fertilization brought about an increase in the C/N ratio of pond bottoms. This increase resulted from a greater proportionate loss of nitrogen over carbon, a greater biochemical replacement of carbon, or a combination of the two processes.

Since the greatest production of fish was associated with the smallest amount of organic and total nitrogen in the water, nitrogen was not a limiting factor.

Introduction

In recent years stress has been laid on the analogy between the production of fish and production from farm soils. Both are crops whose yields are a function of the fertility of their environment. The fish pond is dependent for its natural fertility upon the chemical constituents of the water and those chemical constituents of the pond bottom which make their way into the water by the process of dissolution. As with farm land, the natural fertility of the fish pond can be increased by the addition of fertilizing substances.

In 1919, Von Alten showed that the addition of fertilizer to pond water has an effect on the production of plankton. Wiebe (1929) confirmed this finding and concluded that "the plankton production may be increased through the use of various fertilizers." According to Swingle and Smith (1938) a direct relationship exists between plankton and fish production when inorganic fertilizers are used. Meehean (1939), however, stated that when organic fertilizers are used, phytoplankton is of minor importance as to volume and numbers, and

Swingle and Smith (1939) also concluded that there is not necessarily a direct relationship between the production of plankton and of fish when organic fertilizers are applied. These studies gave rise to the idea that fertilization with inorganic substances results directly in an increased production of plankton, which in turn contributes directly or indirectly to the food of fish and therefore is responsible for an increased production of fish. In the propagation of fingerling largemouth black bass, however, the production of plankton does not necessarily reflect fish production when organic fertilizers such as cottonseed meal are used in limited quantities, for organic fertilizers may be digested by bacteria and the fragments produced in the process along with the bacteria may be utilized by a flourishing population of microcrustaceans closely associated with the bottom, but which never become a part of the plankton. Nevertheless, both fertilizers produce a similar end result, namely, an increase in the production of fish.

Although many studies have been made of the chemical constituents of ponds and lakes, there has been no demonstration of a correlation of these constituents with the production of fish. Birge and Juday (1927) who studied the carbon and nitrogen content of the water of several unfertilized lakes, recorded an average of 0.493 parts per million of organic nitrogen for 84 lakes. Wiebe (1930) made extensive studies of the chemical constituents of fertilized ponds, but made no attempt to correlate his findings with fish production. Meehean (1935) reported that the C/N (carbon/nitrogen) ratio of pond bottoms can be increased by the addition of fertilizers. Meehean, in some unpublished data for seven fertilized ponds, found what seemed to be an inverse relationship between the nitrogen content of the water and fish production.

The present report is based on information obtained from several ponds at the U. S. Fishery Station at Welaka, Florida. These ponds have been used in a study of the relationships between fish production and the application of various fertilizers, and the quantity of some of the chemical constituents of pond waters and pond bottoms. While this report is only preliminary, it is felt that the data are sufficiently suggestive to justify a presentation at this time.

Methods

Sixteen ponds of uniform size (0.6 acre) were used in the present set of experiments. They were fertilized weekly for 3 weeks and then stocked at the rate of 15,000 largemouth black bass (*Huro salmoides*) fry per acre. It is felt that 3 weeks is ample time for the production of an adequate population of microcrustaceans on which the bass feed. Weekly applications of fertilizer were continued for a total of 7 weeks and the fish were finally removed and weighed after 86±3 days. The ponds were filled with water from the St. Johns River, which is slightly alkaline, has a total hardness

of approximately 200 p.p.m., and is slightly colored, probably from humic solutes. The water was pumped into the ponds from a reservoir where it had become slightly acid and the total hardness had been reduced to less than 100 p.p.m.

Two ponds were fertilized weekly with 50 pounds of cottonseed meal[1] per acre. Three groups of three ponds each were fertilized weekly as follows: 50 pounds of cottonseed meal and 33⅓ pounds of colloidal phosphate[2] 50 pounds of cottonseed meal and 83⅓ pounds of lime; 50 pounds of cottonseed meal, 83⅓ pounds of lime and 33⅓ pounds of colloidal phosphate. The remaining five ponds were fertilized with hay. One pond received hay alone. Others received in addition to hay 75 pounds of nitrate of soda, 33⅓ pounds of colloidal phosphate, 33⅓ pounds of colloidal phosphate and 75 pounds of nitrate of soda, or 83⅓ pounds of lime per acre per week for the same period of time as the ponds which were fertilized with cottonseed meal. The hay, which was in excess of that which could be digested, was added at the beginning of the fertilization period.

During the time the fish were in the ponds, samples of pond water were analyzed weekly for 7 weeks and twice monthly thereafter for organic, nitrate, and ammonia nitrogen. These analyses were performed according to methods outlined in "Standard Methods for the Examination of Water and Sewage" (American Public Health Association, 1936).

The pond bottoms were analyzed for carbon and nitrogen prior to the first fertilization, about a month after the last fertilization or just before draining, and a week after the ponds were drained and dried. Since soil was obtained from various parts of the pond, the samples should be representative. The soil was dried in an oven at 60°F., mixed and quartered and then passed through a 60-mesh sieve. The results for each pond represent the average of three separate analyses. Carbon was analyzed according to the method prescribed by Theroux, Eldridge, and Mallman (1936).

In this report, humus is calculated as the carbon content multiplied by the factor 1.7, the nitrogen content multiplied by the factor 20 (Waksman, 1938) or by averaging the results obtained from both of the aforementioned calculations. It should be remembered that the amount of nitrogen applied in the form of fertilizer is only sufficient to produce conditions for the maximum survival of bass fingerlings, and that probably most of this nitrogen is bound up in the biological processes occurring on the pond bottom. The amount of nitrogen applied is not sufficient to yield an excess to the water as is true when farm ponds are fertilized with larger quantities of organic fertilizers or with inorganic fertilizers.

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[1]Contains 36 per cent protein, 5.76 per cent nitrogen.

[2]Contains 25 per cent CaO, 24 per cent P_2O_5, 17 per cent SiO_2, 17 per cent Al_2O_3, and 4 per cent Fe_2O_3. This product is the residue from which phosphate pebbles have been washed. The phosphorus is not as readily available as from superphosphate. The product contains small amounts of Mn, Mg, Cl, Fl, Cr, Va, and Na.

Effects of Different Types of Fertilizer on the Production of Fish, the Loss of Humus, and the C/N Ratio

As shown in Table 1, the average production of fish was increased from 0.49 pounds per acre per day[1] where cottonseed meal was used as a fertilizer to 0.54 pounds with meal and colloidal phosphate, 0.69 pounds with meal and lime, and 0.75 pounds with meal, lime, and colloidal phosphate. These data indicate beneficial results from the use either lime or colloidal phosphate or both with cottonseed meal. The average increase in production was 10 per cent when colloidal phosphate was used with meal, 41 per cent when lime was used with the meal, and 53 per cent when both lime and colloidal phosphate were used with it.

In contrast, the results from the use of minerals with hay as a fertilizer were somewhat different. Considerable variation in the results from these ponds would be expected if only for the reason that only one pond received each specific type of treatment among the ponds fertilized with hay and no definite conclusion should therefore be drawn. It is interesting to note that in this series of ponds colloidal phosphate (Table 2) seemed to be more beneficial as contrasted with lime in the series of ponds fertilized with cottonseed meal. The average production of fish in all ponds frtilized with hay was 0.58 pounds per acre per day as compared with 0.63 pounds in all ponds fertilized with cottonseed meal.

In Table 1 are given the losses of humus which occurred in pond bottoms between the period prior to fertilization and after the last fertilization. (This statement must not be interpreted to mean that fertilization was the *cause* of the loss of humus, for as we shall see later, the net loss of humus in fertilized ponds is small.) These figures are derived from Table 2 which shows the humus content of individual pond bottoms before and after the fertilization of ponds. The losses of humus which occurred in ponds fertilized with cottonseed meal varied inversely with the amount of fish produced. As the production of fish was increased from 0.49 pounds per acre per day to 0.75 pounds, the loss in humus was decreased from 143 milligrams per gram of soil to 64 milligrams as calculated from the nitrogen content. A similar decrease is revealed by the figures calculated from the carbon content of the soil, which show changes ranging from a loss of 67 milligrams to a gain of 3 milligrams. An average obtained from calculations from both the carbon and nitrogen shows these losses to range from 105 to 31 milligrams.

A comparison of all ponds fertilized with hay with those fertilized with cottonseed meal shows that production per acre per day was 0.58 pounds in the former and 0.63 pounds in the latter, and that the corresponding losses of humus were 134 and 94 milligrams as calculated from the nitrogen, 120 and 32 milligrams as calculated from

[1]Meehan (1942) demonstrated the validity of the gain per acre per day as a measure of production.

TABLE 1.—*The effects of fertilizers on the production of fish, the loss in humus content of the pond bottoms, and the amount of nitrogen in the pond water.*

Fertilizer	Number of ponds	Production in pounds per acre per day	Average loss in humus in milligrams per gram of soil (from N calculations)	Average loss in humus in milligrams per gram of soil (from C calculation)	Average loss in humus in milligrams per gram of soil (from average of C and N calculation)	Nitrogen dissolved in the water (p.p.m.)	
						Organic	Total
Cottonseed meal	2	0.49	143	69	105	0.393	0.480
Cottonseed meal and colloidal phosphate	3	0.54	110	48	79	0.348	0.452
Cottonseed meal and lime	3	0.69	73	21	47	0.340	0.412
Cottonseed meal, lime, and colloidal phosphate	3	0.75	64	[1]3	28	0.334	0.394
Hay combinations	5	0.58	157	120	138	0.378	0.488
Cottonseed meal combinations	11	0.63	98	32	65	0.350	0.434
Lowest producing	8	0.50	128	74	101	0.367	0.463
Highest producing	8	0.73	94	44	69	0.350	0.421

[1]Gain.

TABLE 2.—*The effects of fertilizers on both the humus content of pond bottoms and on the production of fish in the pond.*

Pond no.	Fertilizer	Production of fish in pounds per acre per day	Humus, from 1.7 x C in milligrams per gram of soil			Humus from 20 x N in milligrams per gram of soil			Humus from average of both C and N in milligrams per gram of soil		
			Initial	Final	Difference	Initial	Final	Difference	Initial	Final	Difference
7....	Cottonseed meal	0.44	287	281	— 6	282	178	—104	284	229	— 55
13....	do	0.54	265	134	—131	274	92	—182	236	193	— 43
2....	Cottonseed meal and colloidal phosphate	0.68	260	194	— 66	208	102	—106	233	148	— 85
8....	do	0.44	175	230	+ 55	230	146	— 84	202	188	— 14
14....	do	0.50	220	156	— 84	242	100	—142	231	186	— 45
3....	Cottonseed meal and lime	0.67	209	277	+ 68	148	148	0	178	212	+ 34
9....	do	0.84	235	185	— 50	284	112	—172	260	148	—112
15....	do	0.56	165	83	— 82	130	62	— 68	190	156	— 34
4....	Cottonseed meal, lime, and colloidal phosphate	0.73	238	190	— 48	144	118	— 26	191	154	— 37
10....	do	0.81	134	204	+ 70	192	132	— 60	163	168	+ 5
16....	do	0.70	218	204	— 14	222	108	—114	210	231	+ 21
5....	Hay	0.42	417	400	— 17	342	234	—108	379	317	— 62
17....	Hay and lime	0.52	221	173	— 48	218	138	— 80	211	196	— 15
6....	Hay and nitrate	0.55	386	150	—236	290	116	—174	338	137	—201
11....	Hay and colloidal phosphate	0.65	335	148	—187	248	116	—132	257	185	— 72
12....	Hay, nitrate, and colloidal phosphate	0.76	325	201	—124	296	136	—160	310	168	—142

carbon, and 120 and 63 milligrams as calculated from an average of both the carbon and nitrogen content of the soil. Again the losses of humus and the amount of fish production varied inversely.

If the ponds are now arranged into two groups of eight, regardless of the fertilizer used, one of which includes the lowest-producing ponds and the other the highest, the average production was 0.50 pounds per acre per day in the former and 0.73 pounds in the latter group. The losses in humus were respectively 118 and 94 milligrams as calculated from the nitrogen, 74 and 44 milligrams as calculated from the carbon, and 96 and 69 milligrams from the average of the calculations from carbon and nitrogen. These figures furnish further proof for the contention that the greatest production of fish seems to be associated with the smallest losses of humus.

In the light of what has been said, it will be interesting to study the relationship between fish production and the nitrogen content of the water. In a preliminary test, Meehean (unpublished) observed that the total and colloidal nitrogen of the water of seven ponds that were variously fertilized gave a higher average in the lowest-producing ponds. A better example of an inverse relationship between fish production and the nitrogen content of the water is given by the results of the present experiments summarized in Table 1 from the detailed figures of Table 3.

As production was increased from 0.49 to 0.75 pounds per acre per day, organic nitrogen was decreased from 0.393 to 0.334 p.p.m. and the total nitrogen from 0.480 to 0.394 p.p.m. The ponds fertilized with hay, which produced less than ponds fertilized with cottonseed meal, also show a higher average organic content, that is, 0.378 p.p.m. as compared with 0.350 p.p.m. and a higher total nitrogen content or 0.448 p.p.m. as compared with 0.434 p.p.m.

Although it cannot be concluded from these experiments that production of fish in pounds per acre per day *always* varies inversely with the nitrogen content of the water in fertilized ponds, it must at least be assumed that under the present set of conditions, nitrogen was not a *limiting* factor, for an increase in the nitrogen content of the water in these ponds was certainly of no value in increasing production.

In Table 4 are shown the ratios of carbon to nitrogen in pond bottoms before fertilization (C/N_i), after fertilization (C/N_f) and about one week after the ponds were drained and dried (C/N_d).

These figures are taken from the results of determinations of carbon and nitrogen which are listed in Table 5 for individual ponds. Although the initial ratios (C/N_i) were not influenced by the presence of fertilizer, they are somewhat higher than is generally reported for farm land. These high values probably resulted from the fact that our samples were higher in organic debris, for sand (on which these ponds are built) is a more easily removed contaminant (by sift-

TABLE 3.—*The effects of fertilizers on the nitrogen content of pond water for the period during which fish are in water.*

Pond No.	Fertilizer	Nitrogen in p.p.m.				
		Organic-N	NO_3	NO_2	NH_3	Total
7	Cottonseed meal	0.327	0.066	0.0009	0.022	0.416
13	do	0.459	0.062	0.0012	0.022	0.544
2	Cottonseed meal and colloidal phosphate	0.333	0.076	0.0005	0.020	0.430
8	do	0.305	0.004	0.0005	0.008	0.428
14	do	0.407	0.080	0.0013	0.011	0.499
3	Cottonseed meal and lime	0.322	0.062	0.0008	0.012	0.397
9	do	0.358	0.061	0.0012	0.008	0.428
15	do	0.341	0.055	0.0019	0.012	0.410
4	Cottonseed meal, lime, and colloidal phosphate	0.296	0.090	0.0008	0.010	0.397
10	do	0.325	0.068	0.0008	0.012	0.406
16	do	0.382	0.054	0.0022	0.010	0.378
5	Hay	0.341	0.080	0.0009	0.011	0.433
6	Hay and nitrate	0.390	0.083	0.0124	0.022	0.497
11	Hay and colloidal phosphate	0.347	0.096	0.0007	0.012	0.456
17	Hay and lime	0.373	0.097	0.0022	0.006	0.478
12	Hay, nitrate and colloidal phosphate	0.439	0.115	0.0062	0.017	0.577

Table 4.—*C/N ratios of pond bottoms as related to production*

Fertilizer	Number of ponds	Production in pounds per acre per day	Before fertilization (C/N_i)	After fertilizing, before draining (C/N_f)	One week after draining (C/N_d)
Cottonseed meal	2	0.48	11.6	17.9	15.0
Cottonseed meal and colloidal phosphate	3	0.54	12.3	18.9	14.4
Cottonseed meal and lime	3	0.69	13.9	18.7	13.9
Cottonseed meal, colloidal phosphate, and lime	3	0.75	13.1	19.4	14.8
Hay combinations	5	0.58	13.9	16.6	16.9
Cottonseed meal combinations	11	0.63	12.7	18.7	14.5
Lowest producing	8	0.50	12.6	17.0	15.2
Highest producing	8	0.73	13.7	19.2	15.4

ing) than the clay of farm soils, which would be ground up and passed through the sieve.

The fact that the C/N_f ratios were always higher than the C/N_i ratios confirms Meehean's contention (1935) that fertilization results in an increase in the C/N ratio of pond bottoms. The C/N_f ratios seem to be correlated with production, for the average C/N_f ratio was found to rise with increased production (a) when the groups of ponds fertilized with cottonseed meal were compared with one another, (b) when all the ponds fertilized with hay were compared with all the ponds fertilized with cottonseed meal, and (c) when the eight lowest-producing ponds were compared with the eight highest-producing ponds (Table 4).

The higher C/N_f ratio wac brought about largely by a greater proportionate release of nitrogen as compared with carbon during the digestive processes taking place in the bottom deposits or possibly was the result of the larger amount of carbon supplied to the soils by biochemical processes, or a combination of the two. Thirteen times as much nitrogen as carbon was released from the ponds fertilized with cottonseed meal and only twice as much nitrogen as carbon from the ponds fertilized with hay.

Since the C/N_f ratios were generally higher in the most productive ponds, this determination provides a valuable index of the effectiveness of a fertilizer. While the ratio is probably not as reliable as the loss of humus, it is easier to determine because it requires only an analysis after fertilization rather than before and after fertilization as is necessary for the computation of loss of humus.

It is interesting to note that the C/N_d ratio for the drained and dried ponds (Table 4) was lower than the C/N_f ratio, however there is no semblance of a relationship between the C/N_d ratio and production. It is also significant that the carbon and nitrogen content of the

TABLE 5.—*Carbon and nitrogen determinations for pond bottoms for the three sampling periods in miligrams per gram soil*

Pond No.	Carbon in milligrams per gram of soil		Nitrogen in milligrams per gram of soil			
	Before fertilization	After fertilization	After draining	Before fertilization	After fertilization	After draining
7	169	165	217	14.1	8.9	12.1
13	156	79	179	13.7	4.8	14.2
2	153	113	179	10.3	5.1	10.5
8	103	135	137	11.5	7.3	13.6
14	159	80	171	12.1	5.0	10.7
3	123	163	156	7.4	7.4	10.1
9	138	109	123	13.5	5.6	12.6
15	97	49	133	6.5	3.4	8.0
4	140	112	166	7.2	5.9	9.4
10	79	120	125	9.6	6.6	12.7
16	128	120	153	11.1	5.7	9.4
5	268	235	174	17.0	11.7	9.1
6	227	94	221	14.9	5.8	14.2
11	197	87	198	12.7	5.8	9.7
17	130	102	153	10.9	6.9	11.0
12	191	118	144	14.8	6.8	9.1

pond bottoms, both of which were reduced after fertilization, had returned to about the original amounts when the ponds were drained and dried (Table 5). The ponds fertilized with hay did not show as complete return to normal as did those in which the cottonseed meal was used. This fact provides further evidence that hay was not as efficient a fertilizer as the cottonseed meal.

Significance of Experiments on the Fertilization of Fish Ponds

The fertilization of fish ponds is not yet adapted to the needs of fish hatcheries for the reason that the proper requisites for optimum fish production are unknown. However, with the undertaking of investigations regarding the chemical as well as the biological requirements of fish, it is presumed that the time is not far distant when the fertilization of ponds will become an operation of as great precision as is the fertilization of farm land.

It is reasonable to conjecture that the quantities and kinds of fertilizer used in the production of fish will eventually be predictable on the basis of an analysis of the pond bottom and the pond water. It is therefore fitting that studies of this kind be undertaken in increasing numbers as a means of reducing the obstacles which confront the average fish-culturist in the production of fish. It is significant that the production of fish is dependent not only on the amount of carbon and nitrogen which is added as organic fertilizer, but also on the addition of minerals. In these experiments, the same amount of carbon and nitrogen was added to each of 11 ponds in the form of cottonseed meal. Production of fish, however, varied according to whether or not lime, colloidal phosphate or both were used in conjunction with cottonseed meal. A 53 per cent increase in production was brought about when lime and colloidal phosphate were added to cottonseed meal in the ponds.

The results of the present study seem to suggest that in ponds fertilized with organic substances of the variety used here, the increased production of fish is associated with the smallest losses of humus from the pond bottom and with a smaller amount of nitrogen in the water. These statements seem paradoxical for it has always been understood that unfertilized waters derive their fertility from the decomposition of humus and that nitrogen in the water is an essential for the development of water-dwelling forms. However, the fact that the most productive of the fertilized ponds showed the least loss of humus can be interpreted to mean that efficient fertilization has the effect of conserving humus, that there is either no need for a rapid decomposition of humus or that the humus itself is more rapidly replenished when the most efficient fertilizers are used.

In view of the fact that the net loss of humus was less in the most efficiently fertilized ponds, it is not surprising that the nitrogen content of the water also was less, for one must assume that there is a

balance between the release of nitrogen from the pond bottom (by decomposition of humus) and the amount of nitrogen in the water. The fact that a decrease in the nitrogen content of the water does not reflect decreased production is not startling, if we assume, as we must, that in none of these experiments is nitrogen a limiting factor. The preceding explanations of the extraordinary results obtained in this study were not offered with the idea that they must be accepted *de fide,* for we realize their speculative nature. Additional data need to be collected on more heavily fertilized ponds and in bodies of water with a complete natural food cycle.

It should be emphasized that in these experiments only sufficient nitrogen was added to bring about maximum survival of fingerling bass, by creating optimum ecological conditions. This amount required had been determined through years of experience. Far different from this procedure is the use of sufficient fertilizer to create another set of ecological conditions where there is an optimum reduction in population by predators such as is found in farm fish ponds. This situation is produced in farm ponds through the medium of applying nitrogen in larger quantities to produce a water bloom.

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A CRITICAL ANALYSIS OF PRACTICES IN THE MANAGEMENT OF WARM-WATER FISH WITH A VIEW TO GREATER FOOD PRODUCTION

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ABSTRACT

An analysis is made of the commonly used practices in the management of warm-water fish. These practices consist chiefly of legal restrictions, such as closed seasons and creel and size limits, and the restocking of waters from hatcheries or with fish obtained in so-called rescue operations. The value of most of such practices seems to be nil when considered in terms of satisfaction to the angler or increased food production. Some supporting evidence is presented. Suggestions for increasing fish production are: The harvesting of fish crops in proportion to species and sizes available; the rejuvenation of senescent lakes by irrigation; the impoundment of new water areas with provision for managing and harvesting the whole crop; and the utilization of abandoned reclamation projects in a similar manner. The judicious use of irrigation and drainage for the purpose of oxidizing pond bottoms, and the fluctuation of water-levels for reducing shore vegetation and thinning out overly dense populations, are also proposed.

The production of fish for food is not only of great importance during time of war but also during rehabilitation after the war. Natural fish-producing areas are fixed and natural production in them relatively constant as a whole. Therefore, if we want more fish, we must devise better methods of management for these wild areas, or resort to artificial culture, or both. Let us analyze critically the practices in the management of warm-water fish with a view to greater food production and see what prospects lie along these lines.

The public has been educated into believing that certain restrictions —chiefly closed seasons, creel limits, and size limits—are necessary to perpetuate the different species involved. It is surprising that no real scientific evidence has ever been brought forth to substantiate this belief.

The productivity of an area should be measured, not by what exists in it, but by what we take out, that is, by its yield and not its standing crop. Only if this yield can be increased by a closed season or other restrictions are these restrictions justified. Restrictions may be effective for slowly reproducing or readily harvested species, particularly birds and mammals whose annual movements or reproductive cycles make them especially vulnerable at some particular period. Is it necessary, however, to apply the same kind of restrictions to more prolific and less accessible species as many kinds of fishes?

The public has been led to believe also that poor fishing is the result of overfishing. Many personal observations contradict this view. A few years ago I had occasion to go down in the diving bell at Silver

Springs, Florida, where many largemouth black bass were in sight. Thousands of small gizzard shad, *Signalosa,* were swimming in schools near the bass. It was the noon hour, and most anglers know that largemouth bass seldom feed at that time. Occasionally one of the bass started toward the tempting food, then realizing he was not hungry, turned back to his favorite spot amongst the rocks and vegetation. What chance would an angler's lure have under such conditions?

Another experience in the Oceanarium at Marineland, Florida, emphasizes how little we really know of what is going on below the water when we make our observations from above the surface as does the angler when he is fishing. Looking down into the water at midday with a bright sun overhead, hardly a fish could be discerned; yet within the building, when viewing from below the surface, thousands of varicolored fishes of all descriptions were visible.

These experiences, as well as many others, bear out the belief of Eschmeyer (1939) that when a body of water is said to have been fished out by angling, only a relatively small percentage of the fish have actually been removed. Apparently, the majority of fish in a body of water cannot be taken by angling because of the automatic increase in their prey resulting from the removal of part of the stock by the very act of angling. Certainly they cannot be fished out to the point where a shortage of brood stock will occur.

Louisiana had a closed season on several species of fresh-water fish for many years. Those species for which there was no closed season seemed to hold their own as well as those which had the restriction. Not a single bit of evidence was advanced to show that the closed season did any good, and as it was a great irritation to the public, the legislature in 1928 substituted size and creel limits for the closed season. The new law was planned to encourage the taking of mature game fish whenever they would bite. As one female is sufficient to stock many acres of water, there is no profit in rearing a large surplus of fry, only to have them eat each other and in turn be fed upon by their own parents.

A few years ago I was seining some largemouth black bass fry (*Huro salmoides*) at the Fisheries Station at Lacombe, Louisiana. Many fish of fingerling sizes rushed into the seine to fill their stomachs with the fry, and some were preserved with tails protruding from their mouths as evidence. On October 14, 1941, through a confusion of orders, some yearling largemouth bass were placed in the Audubon Park Aquarium in the same tank with some larger specimens of the same species. The former disappeared in less time than it takes to tell it. Thus the largemouth black bass is capable of keeping its numbers reduced to fit the environment whether the sportsmen like it or not.

Every one reading this article ate eggs or seed in some form today. We eat 1,000 grains of corn to every one we plant. If we planted the thousand grains where there is room for only one stalk of corn to grow and mature, we would certainly harvest a smaller crop (if we

harvested any at all) for crowding and disease would soon control the situation. Although fish are far more prolific than corn, most current fishery legislation is designed to save all the eggs for seed in an environment where there is usually space and feed available for only two fish, and where that space is already occupied by the parents of the brood. In many species, the cannibalistic male parent is standing by guarding his future food supply.

Swingle and Smith (1941) stated: "Experiments at Auburn have shown that if only one pair of bream, bass or crappie are present per acre of water, they can produce more small fish than the pond can support." One adult female can produce 5,000 or more young; yet they recommend stocking an acre of water with not over 100 fingerling bass. Those 100 bass should, however, reach a pound each in a year.

Some years ago (1919) about 90 per cent of the salt-water shrimp, *Penaeus setiferus,* existing in the waters along the Louisiana coast were infected with a protozoon disease which destroyed their reproductive organs. Yet during the following two years, 1920 and 1921, the shrimp crops were the largest then known and were greater than for several succeeding years. Thus 10 per cent of the adult shrimp population produced a larger succeeding crop than 10 times their number did the preceding year, while the large 1921 crop again produced a smaller number. This evidence shows that with a prolific species, the food supply and other ecological factors are far more important than the actual number of eggs laid.

In most lakes where closed seasons prevail, anglers complain that when the season opens the water is usually too hot at the surface and fish will not rise, or that mats of algae and other vegetation have formed and entangle their lures and lines; yet they have been deprived of the privilege of fishing when the hungry underfed fish were easiest to catch and should have been removed, not only to make room for the succeeding generation of their own species, but to give the food crops a chance to multiply.

Thompson (1941) stated that lakes recover from overfishing much faster than from underfishing. He explained this situation on the basis of increased food supply for the younger fish which grow faster. Thompson also brought out the fact that in some years 10 times as many fish were produced as in other years, but they were only one tenth the average weight per fish. He attributed the cycle to cannibalism. A dominant brood of crappie devours its own young as well as the young of other species. "This yearly elimination of spawn and young continues until the original dominant brood is so reduced in numbers (almost entirely by natural causes) that the survivors can no longer gather up all the young spawned; then the cycle repeats." His conclusion is that relaxing the restrictions on anglers will tend to produce more fish.

Thompson continued: "In Illinois the fish fauna has been studied as long and as intensively as in any place in the Western Hemisphere,

but there is no evidence that any species has become extinct or depleted as a result of hook-and-line fishing. As a matter of fact, fishing seems to have been better when commercial fishermen were allowed to handle bass, crappies, bluegills, and other 'fine' fish, when there were no hook-and-line licenses, and few of the other restrictions that we have today."

Roberts (1941) reported: "There's a certain reservoir up near Youngstown from which the Ohio Conservation Department for years has been seining bass and bluegills for restocking purposes. No hook-and-line fishing is permitted there, but during the spring, fall, and summer, fish management men go into that lake with nets and take out large numbers of fish.

"A study of the records of these catches show that, for 20 years, the Conservation Division has taken between 100,000 and 175,000 adult fish from these waters annually. The lake's area is about 600 acres. If this water had a fisherman to each six acres, fishing five full months of the year, those fishermen would have to land 10 fish each every day during that time, to come up to the state's catch. For a pond of that size that sort of a take by hook and line would be tremendous.

"Yet such catches have been made, and the breeder population of the lake has remained fairly constant. Never has it been necessary to restock those waters.

"White this example shows benefits to be derived from a policy which allows no overpopulation, there are others to show possible disastrous effects of overpopulation."

Then there is the matter of predation which may come from unexpected quarters. The following is quoted from a personal letter, dated May 19, 1937, from Mr. Cason Callaway with reference to the condition in an artificial lake near Hamilton, Georgia: "Several times I have noticed a bunch of 200 or 300 bream gang a bass, stealing her eggs. This was amazing to me since in some cases the bass will weigh two or three pounds, however, the bream ganged in such numbers that the bass could not handle it.

"I have also noticed bream feasting on young bass fry. Probably my condition is brought about by the lake being over-stocked with bream or by the bream not having sufficient food. It seems to me that hunger is the only thing that would make these bream gang a two or three pound bass."

I have personally investigated the lake referred to and found a tremendous overpopulation of large bluegill sunfish, the result of artificial feeding, chiefly with bread. The black basses, largemouth and native smallmouth, although lean and hungry, were difficult to catch with lures or natural baits because of the gregarious feeding habits of the sunfishes which rushed together in massive schools whenever anything touched the water.

By enforcing unnecessary restrictions, by selective fishing which results in the taking of certain species and sizes, and by other prac-

tices, we have permitted the building up of tremendous populations of undesirable competitors of the very species we wish to protect. Even with some desirable species, as the crappies which live mostly in deep water, only a small fraction of the population is actually harvested under current legislative restrictions.

Next to restrictions, the most widespread fish-management practice employed throughout this land is the restocking of waters, generally with hatchery-reared fish but sometimes by fish taken during so-called rescue operations. My first experience with restocking dates back to my boyhood over 35 years ago. On my father's summer place at Mandeville, Louisiana, was a small clear-water pond, in which were present two large warmouth bass and an assortment of what I now believe were chiefly stunted bluegill sunfish. The warmouths became so tame they would feed out of one's hand and even permit us to remove them gently from the water. We frequently restocked the pond from nearby swamps and ditches, sometimes with hundreds of small sunfish. Yet, in spite of the 12-month closed season and frequent restocking, we never saw any large fish except the two pet warmouth bass. This experience, and the restocking of the swamps in the vicinity, already possessing a plentiful supply of native *Gambusia,* with the same species from Florida, as well as other observations, prejudiced me against restocking practices at an early age.

Although the general feeling, that artificial stocking of waters with warm-water species was a futile practice—effective only as a soothing syrup to quiet the nerves of militant sportsmen's leagues—grew with the years, the accumulation of real statistical evidence on this point has been slow. Some of this evidence, however, is worth mentioning here.

On October 13, 1936, I made a census of the fish population of Virgess Creek, near Forest Hill, Louisiana, by poisoning the 300-foot section of that stream just above its entry into a larger stream, Indian Creek. This stream was selected because it runs past the Beechwood Fish Hatchery and had been stocked with tens of thousands of fry and fingerlings of the largemouth black bass during the previous decade. Only three specimens of that species were taken—an average of one fish to each 100 lineal foot of stream—as against 11 native smallmouth black bass, *Micropterus punctulatus,* in the same section of stream. All three largemouth bass were stunted and of the same age (in their second year of life) and could have been from the previous hatchery crop which was planted in this stream. The smallmouth bass which were never planted, represented age groups from the first to the fifth summer of life. At other times, seine hauls and casting in the larger stream brought forth only the native smallmouth bass. Thus, the species which had never been planted, more than held its own against the heaviest kind of stocking with a species not as well adapted to that type of environment.

On April 11, 1940, several of the older ponds in the Bonnet Carré

Spillway area near New Orleans were stocked with from 1,500 to 9,000 small fingerling largemouth black bass by the Federal government. These ponds had previously been overflowed when the spillway was in operation during the spring of 1937, and there was ample time for their fish populations to become stabilized before they were stocked artificially. During 1941, I fished these same ponds diligently over a period of time but seldom got a response to my lures. At the same time excellent fishing was had in some new ponds dug in the same general area since the spillway was operated in 1937. These particular ponds were neither overflowed by the river nor artificially stocked. However, fish had access to them through shallow ditches during periods of heavy rainfall, or kingfishers carrying fish from the older ponds could have dropped some of the wiggling fish as they passed over the newer ponds.

Census studies were made after pumping some of the ponds dry and by seining in others, and some surprising results were forthcoming. For example, one of the older ponds stocked with 1,500 fingerling largemouth black bass yielded only six stunted individuals of this species weighing a total of 1.85 pounds, as against 12,505 green and bluegill sunfish weighing 201 pounds, or a ratio of sunfish to bass of over 100 pounds to one. Not only did the sunfish population offer severe competition, but the green sunfish is a predatory species well capable of destroying small bass.

In a deeper pond in the same area, which was stocked with 4,500 largemouth bass fingerlings, a mixed crappie population dominated both the black bass and the sunfish. The proportions were 8.4 pounds of crappie and 1.4 pounds of sunfish to each pound of bass. The populations varied greatly from pond to pond in both the old and new series, but the black bass were dominant only in some of the new series, and in every new pond the poundage per acre exceeded that found in any of the older ponds studied. In general, the largemouth bass populations varied in inverse ratio to the combined sunfish and crappie popualtions.

From the practical standpoint of the fishermen, it made no difference whether any of the ponds were artificially restocked or not. A study of this type of evidence completely discredits the idea that artificial restocking will restore the largemouth bass population of a pond dominated by other species. I agree, therefore, with Eschmeyer (1939) who stated that, "Most of the present findings of fishery biologists seem to discount accepted fish management methods—which have been over-sold to the fishing public just as the 'buck law' has been over-sold to the hunter sportsman."

Throughout the long history of fish-culture and management, many explanations have been advanced for the failures to achieve practical results, as measured in terms of angler satisfaction (or shall we say dissatisfaction), by those honest enough to admit failures. Some have stressed lack of restrictions or failure to enforce them; some have

stressed pollution or disease; and others have emphasized predation or objectionable vegetation. Lack of hatchery space, efficient help, or transportation facilities have received a fair share of the blame. Most anglers have blamed the commercial fishermen, but the latter have reciprocated by blaming the anglers. Gars and other predators have been under suspicion for a long time, but the latest fad is populations of stunted fish. To the gullible, it is thunderstorms or outboard motors that have driven the fish to goodness knows where.

Thus there are as many diagnoses as there are diagnosticians, and as many cure-alls as there are sportsman's-league members. Laws are passed, restrictions applied, and legitimate and vital commercial fishing operations hampered. Restocking is resorted to, vegetation is raked, the weather is maligned, and the war on gars goes merrily on. Political promises are made, sometimes actually kept, for on the whole, fish-management practices when reduced to the least common denominator are little more than pork-barrel politics.

But in spite of it all, fluctuation occurs between species while the weight of the fish population as a whole remains static, except after a flood or in newly created waters or newly developed habitats when it increases for a time at a phenomenal rate. In any given fishing area of long standing there is little change in the total poundage of all species harvested, although cycles of abundance and paucity appear amongst some species.

After all, it is environmental conditions, chiefly the available food supply, that govern the size of any fish population. Although the fish manager sometimes has other means at his disposal, the only practical way for the public to help increase the natural supply of feed for the fish he wishes to catch is to catch more fish. The food organisms then increase and the remaining fish have so much more to eat that they soon replace the weight removed by the fishermen. Thompson (1941) showed that even as far north as central Illinois the turnover is so rapid that for every 100 pounds of bass, bluegills, and crappies existing in a body of water, 50 pounds could be removed during the course of a year, without diminishing the standing population of 100 pounds. Thompson estimated also that at latitudes from Jackson, Mississippi, southward, the yields of these "hook-and-line" species could be greater than the carrying capacity of the waters. In other words, if the fishing effort is prolonged so that renewal of lost weight is continuous, a body of water which has a carrying capacity of 100 pounds of these fish could yield 102 pounds annually if located in the latitude of Jackson, Mississippi, and 118 pounds if in the latitude of New Orleans, Louisiana.

If an acre of water can support just so many pounds of fish, and most widely used management practices are no help, what hope is there for increasing fishery production? There loom above all else four possibilities.

First, we must learn how to harvest and utilize crops of fish in

proportion to the species and sometimes to the sizes available. Although every acre of water is producing as many pounds of fish as it has always done under similar ecological conditions, we are not harvesting the whole crop in any water. If we wish our waters to produce more of one species, we must reduce the populations of all others, especially those of undesirable kinds. It makes no difference whether they are predatory or not, all fish remove the same basic chemicals from the environment, and whichever of these chemicals becomes exhausted first determines the weight of the whole standing population of the area. Furthermore, we must reduce the numerical populations of any species we wish to harvest in larger sizes. I have used experimentally the most drastic methods of fishing known to science, and the more drastic the method employed, the quicker a population of large fish of a desirable species could be established.

My second suggestion is the rejuvenation of hundreds of thousands of acres of now senescent lakes by irrigation through old channels of some nearby stream. This procedure is especially feasible on the lower Mississippi River where fertilizer lost from the farms of 30 states could be carried through old distributaries of that stream and spread out through a natural irrigation system over the lakes and wet lands, there to start from the beginning, the cycle of microscopic life so necessary for the production of larger natural crops of fish. I have pointed out (Viosca, 1927 and 1937) the temporary benefits to fisheries resulting from floods and crevasses. The effect is akin to cultivation and fertilization of farm lands, and the physiography of the alluvial plain of the Mississippi, and of the delta in particular, provides the means for large-scale aquicultural development of those areas.

My third suggestion is the impoundment, by means of dams, of suitable areas lying in the flood plains of our rivers and smaller streams. In areas already subject to periodic overflow, thousands of acres can be flooded at small cost per acre. An essential part of this suggestion is that the fishery biologist must be on the site before the engineer, so that plans for complete water-level control and other means for managing the fish population and harvesting the whole crop can be formulated at the outset.

My fourth and last suggestion is the utilization of abandoned reclamation projects in a similar manner. Many additional thousands of acres, now idle, could be brought into intensive fish production within a year.

As newly created impounded waters have a life expectancy of only a few years as prolific sources of fish production, what hope is there for the rejuvenation of these areas? In the juvenile stages of a pond, there is built up of a large living population, with predatory fish as the climax. During this period, an organic accumulation at the bottom is initiated. During the period of senescence, the fish population wanes as air-breathing plants and animals take the place of underwater breathers, and large quantities of organic materials are stored

away in the form of muck or peat. In natural waters, only the utilization of the entire crop will prevent the ultimate storage of its chemical constituents as muck on the bottom or as peat along the shores.

In the management of impounded water areas, including abandoned reclamation projects, nature has given us two inexpensive tools with which to work—fire and water. All engineering practices in connection therewith must be designed to facilitate the use of these tools. Setting a pond on fire is the quickest form of rejuvenation of which I can conceive. In order to accomplish this change, we must be able to drain or pump off every drop of water. The age-old Oriental custom of letting carp ponds remain dry for a period to increase productivity is just as good as it ever was, for, although it was not realized, burning of the bottom mud was accomplished by slower oxidation. After drying for a period, or burning the muck or peat, the area when again flooded is just as good as new. The water will dissolve the stored chemicals from the oxidized muck, and the pond cycle will again begin.

Whenever there is any ingress from outside sources, or survival in underground burrows or low places (and in lowland there usually is) minnows and crawfish appear so rapidly that the uninformed believe they are showered down by the rains. Reacting to this food supply, pan-sized sunfish develop in a few months, quantities of 1-pound black bass are taken within a year, and 2-pound bass within two years. Commercial species grow even faster. When the climax is reached it is time to harvest the crop; hoarding will result in its loss.

If the crop is not harvested, the climax will soon pass. Although larger fish become evident at this time, stunted and parasitized individuals will appear in the population. The numbers of forage fishes now decline rapidly but the more predatory species continue to subsist on stunted individuals of their own or other predatory species. Stimulated by the accumulation of muck, under-water vegetation reaches its climax, affording maximum protection for an ever increasing population of stunted sunfishes. In such a situation black bass and other predatory species will find it harder to get at them and begin to suffer. Even young black bass cannot survive in such a situation because every niche amidst the vegetation is occupied by an educated though usually stunted sunfish. Gars and other predators take over the open areas. It is time to call the doctor.

As the muck accumulates, conditions favor more and more the growth of surface vegetation such as duckweeds, spadderdock, water lilies, lotus, water hyacinths or alligator weed, or a combination of them, depending upon climatic and local factors. Gases rise from the bottom as in a polluted stream. Gars, bowfin, turtles and frogs, being air breathers (the first two when necessity demands) survive this condition better than do the finer food fishes, but the removal of these creatures—merely symptoms of senescence—will not correct the basic condition and make the environment again favorable for the other

species. Shall we call the surgeon now, or wait for the undertaker?

Most natural lakes, of course, are too deep for complete drainage and oxidation of the mud. Some such lakes are subject to partial control by judicious fluctuation of the water level. Lowering the water will kill the higher plant life and draw the small and stunted fish out into the open where they can be thinned out by the predatory population. The resultant thinning out of the populations of plants and small fish and the oxidation of the muck and peat along the exposed shores will stimulate the development of microscopic plants and animals when the high water level is restored. With a good start, the absence of larger plants to absorb the basic chemicals from the soil and water, and the absence of a large population of stunted fish to keep them under control, the food organisms will develop into a tremendous tonnage by the time it is needed by the newly hatched fish.

Such types of management by environmental control show far greater promise than many current practices. There are untold opportunties for the aquicultural development of areas throughout this land which are unsuited for agriculture or forestry. Shall we operate now, or simply prescribe another dose of soothing syrup?

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A PROVISIONAL KEY TO THE SHRIMPS OF THE FAMILY PENAEIDAE WITH ESPECIAL REFERENCE TO AMERICAN FORMS

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Introduction

During the course of the work carried on by the Shrimp Investigations of the Fish and Wildlife Service of the Department of the Interior throughout the past 12 years, it became necessary to prepare a diagnostic key to the species of the shrimps of the Family Penaeidae. As no sufficiently comprehensive key was in existence, one was prepared in order to be able to identify readily the thousands of specimens of a number of species critically examined in the course of the investigation.

The family Penaeidae, from a commercial point of view, is by far the most important family of all the shrimps. In the United States of America it accounts for practically the entire catch which amounts to approximately 150,000,000 pounds annually. Likewise, the family supports a majority of the shrimp fisheries in the remainder of the Americas.

Martin D. Burkenroad, of the Bingham Oceanographic Laboratory, New Haven, Connecticut, has done more to straighten out the confusion existing in the classification of the Penaeidae than any other person who has worked with the family in recent years. We have followed his major groupings, subfamilies, series, and genera, as well as his placement of species in the various genera.

Our key is very largely based on data derived from Burkenroad's published works, in part on the work of others, and on studies which we have made on material at hand and in the collections of the United States National Museum. Secondary sexual characters, which provide one of the best means for the separation of many species, have not been used extensively, for to properly do so would require illustrations. For these details reference should be made to pertinent literature, much of which appears in the "Literature Cited." No doubt errors will be found in some of the characters employed, and others will be found inadequate.

Because a great deal of tedious work and considerable original research have been required for the compilation of this key, it was decided to follow the suggestion of Dr. Waldo L. Schmitt, of the U. S. National Museum, that it be made available for what it it worth to others interested in the problems with which we have been confronted, and in the Family Penaeidae from a taxonomic point of view.

We also wish to acknowledge the helpful cooperation extended us on all occasions by the authorities of the United States National Museum.

KEY TO SUB-FAMILIES OF THE FAMILY PENAEIDAE

I. Post orbital spine present. Cervical sulcus extending nearly or to the dorsum of the carapace. Tuft of setae on proximal margin of propodus of first pereiopods. Pleurobranchs present behind IX. Scale at external angle of ocular somite. Epipodites on all coxae from VIII through XIII.

SOLENOCERINAE Wood-Mason and Alcock

II. Post orbital spine absent.

A. Tuft of setae on proximal margin of propodus of first pereiopods. Pleurobranchs present behind IX. Exopodites present on the maxillipeds and pereiopods.

a. Distinct median tubercle on ocular peduncle. Epipodites on all coxae from VIII to XIV. No scale at external angle of ocular somite. A functional, filamentose anterior arthrobranch on XIII. Cervical sulcus usually extending to dorsum of carapace.

ARISTAEINAE Alcock

aa. No median tubercle on ocular peduncle. Epipodites absent behind XII. Scale present at external angle of ocular somite. No functional filamentose anterior arthrobranch on XIII except reduced form in *Artemesia.* Cervical sulcus does not extend to dorsum of carapace.

PENAEINAE Burkenroad

AA. Tuft of setae absent from proximal margin of propodus of first pereiopods. Pleurobranchs absent behind IX. Exopodites absent from the maxillipeds and pereiopods. No scale at external angle of ocular somite.

EUSICYONINAE Burkenroad

KEY TO GENERA OF SUB-FAMILY SOLENOCERINAE WOOD-MASON

I. Antennular flagella flattened or hollowed out, channel-like in structure.

Solenocera Lucas

II. Antennular flagella cylindrical and filiform.

A. Podobranchs present on segments posterior to VIII. Telson with several pairs of mobile lateral spines forward the distal fixed pair. Prosartemia of inner edge basal segment of antennular peduncle but a rigid short projection.

Haliporus Bate

AA. Podobranchs absent behind VIII. Only a single pair of lateral telson spines. Prosartemia of inner edge basal segment of antennular peduncle a long flexible scale.
Hymenopenaeus Smith

Key to the Species of the Genus *Solenocera* Lucas

I. Branchiostegal and pterygostomian spines absent.
  A. Tooth or spine present on the externodistal margin of the exopod of the uropod.
    a. With dorsal carapacic spine posterior to the cervical groove.
    S. steindachneri (Balss)—Indo Pacific

    aa. Without dorsal carapacic spine posterior to the cervical groove.
      1. Postrostral carina not crossing the level of the cervical groove.
      S. weymouthi Linder and Anderson[1]—Atlantic American

      2. Postrostral carina extending nearly to the posterior margin of the carapace.
      S. melantho DeMan—Indo Pacific

  AA. Tooth or spine absent from the externodistal margin of the exopod of the uropod.
    a. Spine present on cervical groove ventral to posteriormost spine of rostral series.
    S. hextii Wood-Mason—Indo Pacific

    aa. Spine absent from cervical groove.
      1. Postrostral carina reaching to posterior portion of the carapace. Small spine or tooth present in orbital angle.
      S. koebeli DeMan—Indo Pacific

      2. Postrostral carina not extending behind level of cervical groove. No spine or tooth in orbital angle.
        a'. Petasma of male with series of large comblike spines on outer surfaces of distolateral lobes.
        S. pectinatus (Bate)—Indo Pacific

        a'a'. Petasma of male without series of large combline spines on outer surfaces of distolateral lobes.
        S. rathbuni Ramadan—Indo Pacific

II. Branchiostegal spine present but without a pytergostomian spine.
  A. Telson without lateral armature.
  S. crassicornis H. Milne Edwards—Indo Pacific

[1]According to Burkenroad (correspondence) it is likely that this species is identical with *Hymenopenaeus tropicalis* (Bouvier).

AA. Telson with lateral armature.

a. No tooth or spine in orbital angle.

S. faxoni DeMan—Indo Pacific

aa. With tooth or spine in orbital angle.

S. annectans Wood-Mason and Alcock—Indo Pacific

III. Pterygostomian spine present but without a branchiostegal spine.

A. Species limited to Atlantic America.

a. Rostral teeth 8 to 10, usually 9. Postrostral carina high and sharp, deeply notched at level of cervical groove.

S. vioscai Burkenroad

aa. Rostral teeth 5 to 7, usually 6. Postrostral carina low or absent, only slightly depressed at level of cervical groove.

1. Antennal scale long, exceeding antennular peduncle by at least 13 per cent its own length. No well defined tooth at orbital angle. Pterygostomian spine large with wide base, joining carapace in a gentle curve.

S. necopina Burkenroad

2. Antennal scale short, less than antennular peduncle to exceeding antennular peduncle by about 8 per cent of its own length. A well defined tooth at orbital angle. Pterygostomian spine small with narrow base, joining carapace at approximately a right angle.

S. atlantidis Burkenroad

AA. Species limited to Eastern Atlantic and South Africa.

a. Cervical sulcus bending ventrad in a sharp angle at its anteroventral termination.

S. membranacea (H. Milne Edwards)—Eastern Atlantic

aa. Cervical sulcus does not curve sharply at its anterior end.

S. m. africanus Stebbing—South Africa

Considerable confusion seems to prevail as to the identity of specimens that have been called *S. africanus* Stebbing.

AAA. Species limited to the Indo Pacific.

a. Hepatic spine placed very low on sides of carapace. Orbital angle dentiform.

S. novae-zealandiae Borradaile

aa. Hepatic spine not placed very low on sides of carapace. Orbital angle not dentiform.

S. comatus Stebbing—Indo Pacific

AAAA. Species limited to Pacific America.

a. Rostral teeth 8 to 10, usually 9. Peterygostomian spine joining carapace in a gentle curve.

S. agassizii Faxon

aa. Rostral teeth 6 to 8, usually 7. Peterygostomian spine joining carapace at approximately a right angle.

1. 13th sternite of female acutely concave on the posterior margin. Petasma of male with median lobule of distolateral lobe a subrectangular shape.

S. florea Burkenroad

2. 13th sternite of female rounded convex on posterior margin. Petasma of male with median lobule of distolateral lobe a subtriangular shape.

S. mutator Burkenroad

KEY TO THE SPECIES OF THE GENUS *Haliporus* BATE

I. A parapeneid spine present on the median margin of the basal segment of the antennular peduncle. Merus of first legs armed with a stout spine.

H. thetis Faxon—Pacific Ocean

II. No parapeneid spine present on the median margin of the basal segment of the antennular peduncle. Merus of first legs without a stout spine.

H. curvirostris Bate—Pacific Ocean

KEY TO THE SPECIES OF THE GENUS *Hymenopenaeus* SMITH

I. Branchiostegal and pterygostomian spines absent. No postrostral teeth separated from the rostral group.

A. Epipods of VIII and IX furcated.

H. tropicalis (Bouvier)—Atlantic America

AA. Epipods of VIII and IX not furcated.

H. mulleri (Bate)—Atlantic America

II. Branchiostegal spine present, pterygostomian spine absent. No postrostral teeth separated from the rostral group.

A. Orbital angle with tooth or spine.

H. robustus Smith—Atlantic America

AA. Orbital angle without tooth or spine.

a. Merus of first legs not armed. Species limited to Atlantic America.

H. modestus Smith

aa. Merus of first legs armed with a stout spine. Species limited to Indo Pacific.
H. lucasii Bate

III. Pterygostomian spine present, branchiostegal spine absent. One postrostral tooth that is separated from the rostral group.

A. Species occurring in South African waters.

a. One species, **H. triarthrus** (Stebbing).

AA. Species occurring in Pacific

a. Merus of first legs armed with a stout spine.
H. diomedeae (Faxon)

aa. Merus of first legs unarmed.
H. sibogae (DeMan)

IV. With branchiostegal spine, with or without pterygostomian spine. With two postrostral teeth separate from the rostral group.

A. With pterygostomian spine.

a. Species occurring in the Atlantic.

1. One species, **H. laevis** (Bate)

aa. Species occurring in Pacific America.

1. Two species, **H. mereus** (Faxon) and **H. doris** (Faxon). Separation of these two forms is not attempted but **H. doris** has been figured with a tooth on the postrostral carina posterior to the cervical suture.

AA. Without pterygostomian spine.

a. Species occurring in the Atlantic

1. Eye from dorsolateral view with respect to shape of cornea and position of tubercle as figured by Burkenroad 1936, page 113. No photophores present.
H. aphoticus Burkenroad

2. Eye from dorsolateral view with respect to shape of cornea and position of tubercle as figured by Burkenroad 1936, page 123. Photophores present.
H. debilis Smith

aa. Species occurring in the Indo Pacific.

1. Third and possibly first and second pleonic somites carinated.
H. propinquus (DeMan)

2. First, second and third pleonic somites not carinated.

a′. First leg with basis unarmed.
H. aequalis (Bate)

a'a'. First leg with basis armed.

1'. Fourth, fifth and sixth pleonic somites with posteriomedian dorsal tooth. Ischium unarmed.

H. neptunus (Bate)

2'. Fourth and fifth pleonic somites without posteriomedian dorsal tooth. Ischium armed.

H. obliquirostris (Bate)

V. Branchiostegal and pterygostomian spines both present. No postrostral teeth separate from the rostral group.

H. villosus (Alcock and Anderson), Pacific

VI. With pterygostomian spine, without branchiostegal spine. No postrostral teeth separate from the rostral group.

H. taprobanensis (Alcock and Anderson), Pacific

KEY TO SERIES OF THE SUB-FAMILY ARISTAEINAE ALCOCK

I. Distal, filamentous portion of the superior antennular ramus extensively developed.

Series **Benthesicymae** Bouvier

II. Distal, filamentous portion of the superior antennular ramus not extensively developed.

Series **Aristeae** Bouvier

KEY TO GENERA OF THE SERIES BENTHESICYMAE BOUVIER

I. Fourth and fifth legs with dactyls long and multiarticulated (similar to *Xiphopenaeus*).

Benthonectes Smith

II. Dactyls of the fourth and fifth legs not long and multiarticulated.

A. Podobranchs lacking behind VIII. Gill of somite VII reduced to a vestige. Telson armed with only a single pair of mobile lateral spines.

Gennadas Bate

AA. Podobranchs present on somites VIII to XII. Gill of VII not reduced to a vestige. Telson armed with more than a single pair of mobile lateral spinules.

a. "Pleonic terga in advance of XX uncarinated. Exopod of the first maxillipede without a constricted, segmented distal portion. Telson with more than a single pair of mobile lateral spinules but without a posteriomedian point."[2]

Bentheogennema Burkenroad

[2]Burkenroad, 1936, page 56.

aa. "Pleonic terga in addition to that of XX carinated. Exopod of the first maxillipede distally constricted and segmented. Telson with four pairs of mobile lateral spinules: a small posteriomedian point usually present."[3]
Benthesicymus Bate

THE GENUS *Benthonectes* SMITH

1 species—***B. filipes*** Smith. East Coast of United States and Pacific.

KEY TO SPECIES OF THE GENUS *Gennadas* BATE[4]

"It is found that in all species of *Gennadas* with independent spermathecal orifices the distolateral lobe of the petasma is entire, not sub-divided; whereas in all species with orifices contained within a common atrium, the distolateral lobe is bifurcated. The subdivision of the genus here proposed is based upon this correlation.

A Key to the Adult Petasma and Thelycum of the Species of ***Gennadas*** Bate[5]

Group I. Male. Distolateral lobe of the petasma undivided.
Female. Orifices of the seminal receptacles opening independently, not included in a common atrium.

IA. Male. Distoventral lobe of the petasma undivided.
Female. Orifices of the receptacles not guarded posteriorly by large and conspicuous prominences. Orifices widely separated, the distance between them as great or greater than that between the apertures and the anterior margin of sternite XIV.

IA1. Male. Distolateral lobe not so wide as the distoventral; accessory lobe of petasma projecting far above the distal margin.
Female. Unknown.
1. ***G. sordidus*** Kemp; Balss, 1927 (male).

IA2. Male. Distolateral lobe much wider than the distoventral; accessory lobe not reaching above the distal margin.

IA2a. Male. Both lobules of the distomedian lobe armed with truncated spines; accessory lobe slender and clavate, arising far mediad the lateral margin of the distomedian lobe.

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[3]Burkenroad, 1936, page 23.
[4]All of the following material relative to *Gennadas* is copied direct from Burkenroad 1936, pages 64-66.
[5]Dated references are to works of previous students containing satisfactory figures of the species in question. Bracketed references to numbered figures indicate illustrations in the present paper.

Female. Transverse elevation of the poterior margin of XII w-shaped; XIII without a rectangular elevation.

2. ***G. capensis*** Calman, 1925, male [female, figure 53, p. 70].

IA2b. Male. Median lobule only of the distomedian lobe armed; accessory lobe broad, arising laterad the lateral margin of the distomedian lobe.

Female. Transverse elevation at the posterior margin of XII Λ-shaped; XIII with a conspicuous rectangular elevation the anterolateral corners of which overlap the posterior lips of the orifices of the sperm-receptacles.

3. ***G. kempi*** Stebbing, Balss, 1927, male [female, figure 54, p. 70.]

IB. Male. Distoventral lobe of the petasma divided.

Female. Orifices of the sperm receptacles guarded posteriorly by large and conspicuous prominences; orifices not widely separated, distance between them less than that between apertures and anterior margin of XIV.

IB1. Male. Distomedian lobe not reaching so far distad as the distoventral; accessory lobe much less than half as broad as the distoventral.

Female. Posterior portion of XIII, behind the level of the posterior lips of the spermathecal orifices, without a shield-shaped median elevation with anteriorly directed apex.

4. ***G. elegans*** (Smith), 1882, male [female, figure 55, p. 70].

IB2. Male. Distomedian lobe reaching farther distad than the distoventral; accessory lobe more than half as wide as the distoventral.

Female. Posterior portion of XIII with strong anteriorly directed median elevation.

IB2a. Male. Cleft between the lobules of the divided distoventral lobe extending farther proximad than the cleft between the distoventral and distolateral lobes.

Female. Apex of the median plate of XIV considerably overlapping the base of the median plate of XIII.

5. ***G. brevirostris*** Bouvier; Balss, 1927, male and female (sub ***G. similis***).

IB2b. Male. Cleft of the distoventral lobe not so deep as that between distoventral and distolateral.

Female. Median plate of XIV not overlapping that of XIII.

IB2b(1). Male. Distolateral lobe broader than the distoventral, and reaching as far distad as it does; accessory lobe smaller than the distolateral, and entire.
Female. XIV without a median longitudinal ridge.
6. ***G. tinayrei*** Bouvier, 1908, male [female, figure 56, p. 70.]

IB2b(2). Male. Distolateral lobe much narrower than the distoventral, and not reaching so far distad as does the latter; accessory lobe much larger than the distolateral, and tripartite.
Female. Elevation of XIV with a median longitudinal ridge.
7. ***G. parvus*** Bate; Balss, 1927, male and female.

Group II. Male. Distoventral and distolateral lobes of the petasma both divided.
Female. Orifices of the sperm receptacles lying within a common atrium.

IIA. Male. Lobules of the distolateral lobe subequal in breadth.
Female. A transverse pair of conspicuous tooth-like projections on XIII.

IIA1. Male. Lobules of the distolateral lobe curved toward one another and acuminated.
Female. Posterior margin of XII produced backward over XIII, as a large free flap buttoned into place by the widely separated pair of projections of XIII.
8. ***G. bouvieri*** Kemp, 1909, female; Balss, 1927, male (sub. ***G. alcocki***).

IIA2. Male. Lobules of the distolateral lobe not hooked and acuminated.
Female. Posterior lip of XII not much produced; projections of XIII extending to or nearly to the midline.

IIA2a. Male. Lateral lobule of the distoventral lobe longer than the median; lobules of the distolateral lobe short and stout, the cleft between them not half as deep as that between distoventral and distolateral lobes.
Female. Paired projections of XIII not meeting in the midline; not reaching nearly to the anterior margin of XIII.
9. ***G. valens*** (Smith) 1884, male [female, figure 57, p. 79].

IIA2b. Male. Median lobule of the distoventral lobe longer than the lateral; lobules of the distolateral lobe long and slender, the cleft between them more than half as deep as that between distoventral and distolateral lobes.

Female. Paired projections of XIII meeting in the midline; reaching nearly to the anterior margin of XIII.

10. ***G. gilchristi*** Calman, 1925, male [female, figure 58, p. 79].

IIB. Male. Lobules of the distolateral lobe very unequal in breadth.

Female. No transverse pair of toothlike projections on XIII.

IIB1. Male. Distoventral lobe much longer than the distolateral.

Female. Interspace between the orifices of the sperm receptacles, within the atrium. not elevated as a conspicuous longitudinal ridge; XIII with a single elevation not separated into anterior and posterior parts.

11. ***G. incertus*** Balss, 1927, male (and female, sub ***G. gardineri***).

IIB2. Male. Distoventral lobe much shorter than the distolateral.

Female. Atrium between XII and XIII divided by a well-defined median longitudinal ridge; XIII with distinct anterior and posterior elevated areas.

IIB2a. Male. Lateral lobule of the distolateral lobe much broader than the median one.

Female. Elevated area of XIII weakly separated into a short anterior and a long posterior portion by a shallow transverse sulcus.

12. ***G. talismani*** Bouvier; Balss, 1927, male [female, figure 60, p. 79].

IIB2b. Male. Lateral lobule of the distolateral lobe much narrower than the median.

Female. XIII with distinct anterior and posterior elevations.

IIB2b(1). Male. Lateral lobule of the distoventral lobe broader than the median; median lobule of the distolateral lobe not acuminated.

Female. A free flap projecting forward from the anterior margin of XIV nearly to the anterior margin of XIII.

13. ***G. scutatus*** Bouvier, 1908, male [female, figure 59, p. 79].

IIB2b(2). Male. Lateral lobule of the distoventral lobe narrower than the median; median lobule of the distolateral lobe tapering to a narrow tip.

Female. No free projection from XIV.

14. ***G. propinquus*** Rathbun; Balss, 1927, male (sub ***G. scutatus indicus***); Kemp, 1910 b, female (sub ***G. alcocki***)."

DISTRIBUTION OF SPECIES OF THE GENUS *Gennadas*

G. sordidus Kemp—Indo Pacific
G. capensis Calman—Atlantic
G. kempi Stebbing—?
G. elegans (Smith)—Atlantic
G. brevirostris Bouvier—Atlantic
G. tinayrei Bouvier—Atlantic and Indo Pacific
G. parvus Bate—Indo Pacific-Atlantic
G. bouvier Kemp—Atlantic and Pacific
G. valens (Smith)—Atlantic
G. gilchristi Calman—?
G. incertus Balss—?
G. talismani Bouvier—Atlantic
G. scutatus Bouvier—Atlantic and Pacific
G. propinquus Rathbun—Indo Pacific

KEY TO SPECIES OF THE GENUS *Bentheogennema* BURKENROAD

I. Cervical and post-cervical sutures very closely approximating each other dorsally.

B. pasithea (DeMan)—Pacific

II. Cervical and post-cervical sutures not closely approximating each other dorsally.

A. Cervical and post-cervical sutures not interrupting the post-rostral carina.

B. borealis (Rathbun)—North Pacific

AA. Cervical and post-cervical sutures interrupting the post-rostral carina.

B. intermedia (Bate)—Atlantic & Pacific

One other species ***B. stephenseni*** Burkenroad, was preliminarily described by Burkenroad 1940. He states it is closely related to ***B. intermedia*** (Bate).—"Dana" Station 3624 I.

KEY TO SPECIES OF THE GENUS *Benthesicymus* BATE[6]

"Sixteen species of the genus (not including the three added in the present paper) have been described, the validity of only seven of which is certain. Aside from the lack of exact knowledge of intraspecific variation which is responsible for the difficulties of synonymy, scant information has been available even as to the differences between the seven clearly distinct species or superspecies. Disregarding for the present the question, whether the ***Benthesicymus brasiliensis*** and ***B. crenatus*** groups contain one or many species, the structural relationships within the genus may be described as follows:

Synopsis of the Genus Benthesicymus

Group I. Thelycum without well-defined receptacles between the twelfth and thirteenth sternites, the scutes of the twelfth and thirteenth sternites being simple and unexpanded. Distoventral lobe of the petasma separated from the distolateral by a deep notch. Median margin of the petasma unarmed, the cincinnuli being borne on a ridge extending up the anterior face of the organ. Exopod of the first maxillipede narrowing abruptly to the segmented distal portion. Merus of the second maxillipede expanded, less than three times as long as broad (except in ***B. strabus,*** n. sp.). Dactyl of third maxillipede triangular, with no more than one strong spine at the tip. Exopodites of the walking legs small but easily perceptible. Pterygostomian spine, in lateral veiw, placed at the margin of the carapace. Pterygostomian carina not sharp.

IA. Posterolateral margins of the fourth pleonic tergite without a comblike series of strong serrae. Antennal carina strong. Cardiacobranchial carina turning ventrally in its posterior part, ending below the posterolateral shoulder of the carapace. First chelipeds without a slender, well-defined tooth at distal ends of basis and ischium.[7]

IA1. Hepatic tooth present. Pterygostomian carina very weak and not extending posteriorly as far as the level of the hepatic buttress. A moderately strong tooth on the ventrolateral margin of the sixth pleonic segment, just anterior to the postero-ventral angle. Tooth of the first pelonic sternite small or absent. Merus of second maxillipede only moderately expanded, more than two and

[6]All of the following material relative to *Benthesicymus* is copied direct from Burkenroad 1936, pages 23 to 25, 45, 46.

[7]In all of these features the two species of Section IA agree with Group II, except that the antennal carina is there weaker, though variable (ranging in strength from moderate in *B. bartletti* to absent in *B. investigatoris*).

one-half times as long as broad.[8] ***B. brasiliensis*** Bate and related forms (cf. ***B. cereus***).

IA2. Hepatic tooth absent. Pterygostomian carina obtuse but well-defined, and extending far behind the level of the hepatic buttress. No tooth on the ventrolateral margin of the sixth pleonic segment. Tooth of the first pleonic sternite very strong. Merus of second maxillipede considerably expanded, only about twice as long as broad. ***B. carinatus*** Smith

IB. Posterolateral margins of the fourth pleonic tergite with a comblike series of strong serrae. Antennal carina absent. Cardiaco-branchial carina not turning ventrally at its posterior end, terminating at the level of the posterolateral shoulder of the carapace. First cheliped armed on basis and ischium.

Hepatic tooth absent. Pterygostomian carina very weak, and not extending posteriorly as far as the level of the hepatic buttress. A strong tooth on the ventrolateral margins of the sixth pleonic segment. Tooth of the first pleonic sternite very strong. Merus of second maxillipedes strongly expanded, less than twice as long as broad. ***B. crenatus*** Bate[9] and related forms

Group II. Thelycum with well-defined cavities between the twelfth and thirteenth sternites, the scute of the thirteenth sternite being broadly expanded to overlap the sternal surface proper. Distoventral and distolateral lobes of the petasma not sharply separated. Median margin of the petasma cincinnulated. Exopod of the first maxillipede tapering gently to the tip. Merus of the second maxillipede unexpanded, not less than three and one-half times as long as broad. Dactyl of third maxillipede subrectangular, the distal margin bearing more than one strong spine. Exopodites of the walking legs very minute. Pterygostomian spine, in lateral view, set behind the margin of the carapace. Pterygostomian carina very sharply defined.

IIA. Ocular peduncle not much longer than the cornea is broad; ocular tubercle situated near distal end of median margin of peduncle. Scute of the thirteenth sternite of the female posteriorly overlapping the fourteenth sternite, anteriorly not projecting free in the midline. Dis-

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[8] In all of these features, the *B. brasiliensis* complex differs from the species of Group II, although in degree of expansion of merus of second maxillipede it approaches Group II more closely than do the other species of Group I.

[9] Diagnosis derived from an Hawaiian male, which differs from Bate's description in several of the features mentioned (see succeeding paragraphs).

[10] The more median part of the distoventral lobe, which in the Benthesicymae surmounts the more lateral portion of the lobe.

toventral *projection*[10] of the petasma not rising much above the distoventral *flap.*[11]

Accessory lobe of the petasma rudimentary. Fifth and sixth pleonic tergites with a short strong tooth at the posterior midmargin.

B. investigatoris Alcock and Anderson

IIB. Ocular peduncle about twice as long as the cornea is broad; ocular tubercle at or proximal to the middle of the median margin of the peduncle. Posterior margin of the scute of thirteenth sternite of the female not overlapping the fourteenth; anterior part projecting free in the midline. Distoventral projection of the petasma rising considerably above the distoventral flap.

IIB1. Distoventral lobe of the petasma not rising very high above the distolateral; accessory lobe fairly well developed and with denticulate margin. Fifth and sixth pleonic tergites not terminating in a tooth; posterior margin of the sixth tergite upturned.

B. altus Bate

IIB2. Distoventral lobe of the petasma rising conspicuously above the distolateral as a slender projection; accessory lobe very weak.

IIB2a. Fifth and sixth pleonic tergites with a short, strong tooth at the posterior midmargin. ***B. tanneri*** Faxon.

IIB2b. Fifth pleonic tergite with a long slender tooth springing from the middle of its length; sixth pleonic tergum armed very weakly or not at all. ***B. bartletti*** Smith."

"*Key to the Species of the* B. brasiliensis *Complex*

I. Posterior margin of the fourth pleonic tergite armed with a tooth. Posterior rostral tooth usually behind the level of the orbital margin.

IA. Posterior margin of the third pleonic tergite armed with a tooth; tooth of the fourth tergite not greatly enlarged. Interval between penultimate and antepenultimate lateral spines of the telson more than twice as great as that between penultimate and ultimate pairs. Anterior blade of appendix masculina not broadest at the base.

B. brasiliensis Bate

Figures 2 and 3, p. 31; 14, 15 and 16, p. 36; 21, p. 37; 26, p. 39; 31, p. 40; 38, p. 41.

[11]The distal end of the lateral margin of the petasma, in Benthesicymae separated from the distoventral projection by a more or less conspicuous notch; in *Metapenaeopsis* greatly produced to form a spiral coil (cf. Burkenroad, 1934 b).

IB. Posterior margin of the third pleonic tergite unarmed; tooth of the fourth much larger than that of the succeeding tergites. Interval between penultimate and antepenultimate less than one and one-half times as great as that between penultimate and ultimate spines. Anterior blade of appendix masculina very wide at base.

B. urinator, n. sp.

Figures 4 and 5, p. 31; 9, p. 35; 17 and 18, p. 36; 32 and 33, p. 40; 39 and 40, p. 41; and 45, p. 42.

II. Posterior margin of the fourth pleonic tergite unarmed. Posterior rostral tooth usually anterior to the level of the orbital margin.

IIA. Merus of the second maxillipede more than three and one-half times as long as broad. Cornea nearly as broad as the ocular peduncle is long; ocular tubercle nearly at level of the proximoventral corneal margin. Posterior blade of the appendix masculina distally much expanded.

Posterior margin of the sixth pleonic tergite armed with a tooth. Interval between the proximal lateral spine and the distalmost of the basolateral emarginations of the telson less than the interval between the distal and the penultimate emarginations.

B. strabus, n. sp.

Figures 10, p. 35; 23, p. 37; 27, p. 39; 34, p. 40; 41, p. 41; 46, p. 42; 49, p. 43.

IIB. Merus of the second maxillipede less than three times as long as broad. Cornea not nearly so broad as ocular peduncle is long; ocular tubercle far proximad the cornea. Posterior blade of the appendix masculina not considerably expanded at the tip.

IIB1. Posterior margin of the sixth pleonic tergite armed with a tooth. Breadth of antennal scale usually less than one-third the length. Interval between proximal lateral spine and the distalmost of the basolateral emarginations of the telson usually less than one and one-third times the interval between the distal and the penultimate emarginations. ***B. cereus,*** n. sp.
For list of figures see p. 30.

IIB2. Posterior margin of the sixth pleonic tergite unarmed. Breadth of antennal scale usually more than one-third third the length. Interval between proximal spine and distal emargination usually more than one and one-

third times the interval between the distal and the penultimate emarginations.

B. iridescens Bate

Figures 7, p. 31; 13, p. 35; 20, p. 36; 25, p. 37; 29 and 30, p. 39; 36 and 37, p. 40; 43 and 44, p. 41; 48, p. 43."

Distribution of Species of the Genus *Benthesicymus*

B. brasiliensis Bate (Atlantic)
B. urinator Burkenroad (Indo Pacific)
B. strabus Burkenroad (South Pacific)
B. cereus Burkenroad (Atlantic-Pacific)
B. iridescens Bate (Atlantic-Pacific)
B. carinatus Smith (Atlantic-Pacific)
B. crenatus Bate (Atlantic-Indo Pacific)
B. investigatoris Alcock & Anderson (Indo Pacific)
B. altus Bate (Atlantic-Pacific)
B. tanneri Faxon (Pacific America)
B. barletti Smith (Atlantic-Pacific)

Key to Genera of Series Aristeae Bouvier

I. Hepatic spine present.
  A. Podobranch on twelfth and epipodite on thirteenth reduced to a rudiment or absent.

Hepomadus Bate

  AA. Podobranch on twelfth and epipodite on thirteenth well developed.

Aristaeomorpha Wood-Mason

II. Hepatic spine absent.
  A. Epipodite on XIII. Podobranch present on XII although it may be rudimentary.
    a. Epipodite on XIII rudimentary. A small podobranch on XII.

Hemipenaeus Wood-Mason

    aa. Epipodite on XIII large. Podobranch on XII large. Rostrum tridentate.

Plesiopenaeus Bate

  AA. Epipodite absent from XIII. No podobranch on XII.

Aristaeus Duvernoy

Key to Species of the Genus *Hepomadus* Bate

I. Fourth and fifth pleonic somites with teeth at posterior ends of dorsal carinae.

H. glacialis Bate—Pacific

II. Fourth and fifth pleonic somites without teeth at posterior ends of dorsal carinae.

H. tener Smith—Atlantic

THE GENUS *Aristaeomorpha* WOOD-MASON

Possibly only one species, ***A. foliacea*** (Risso), which may be identical with ***A. rostidentata***—Atlantic & Pacific.

KEY TO SPECIES OF THE GENUS *Hemipenaeus* BATE

I. No large spine springing from the third pleonic tergum.

H. speciosus Bate—Southern South Atlantic

II. A large spine springing from the third pleonic tergum.

A. Rostrum short being less than one-fifth as long as the carapace and not reaching the end of the eye.

H. carpenteri Wood-Mason—Indo Pacific and Atlantic

AA. Rostrum at least one-fifth as long as its carapace and reaching end of eye.

H. spinidorsalis Bate—Indo Pacific and Atlantic

Three other species in the genus:

1. ***H. crassipes*** Wood-Mason—Indo Pacific.
2. ***H. gracilis*** Bate—Indo Pacific.
3. ***H. sibogae*** DeMan—East Indian Archipelago.

KEY TO SPECIES OF THE GENUS *Plesiopenaeus* BATE

I. Second maxilliped with exopod nearly twice as long as the endopod.

P. edwardsianus (Johnson).—Atlantic and Pacific

II. Second maxilliped with exopod either shorter or not much longer than the endopod.

A. Second maxilliped with exopod not much longer than the endopod. Merus of first legs with mobile spine. Basis and ischium of first legs without fixed tooth.

P. coruscans (Wood-Mason).—Atlantic and Pacific

AA. Second maxilliped with exopod considerably shorter than the endopod. Merus of first and second legs with mobile spine. Ischium of first legs with strong tooth.

P. armatus (Bate).—Atlantic and Pacific

THE GENUS *Aristaeus* DUVERNOY

Evidently 5 species are included:

A. antillensis Bouvier—West Atlantic.
A. antennatus (Risso)—Mediterranean and East Atlantic.
A. occidentalis Faxon—West Coast of Central America.
A. semidentatus Bate—Indo Pacific.
A. virilis Bate—Indo Pacific.

Key to Groups of the Sub-family Penaeinae

I. A pleurobranch on the fourteenth somite. Epipodite present on the third maxillipeds. Ventral rostral teeth in many or all of the species of all genera.

Penaeus group

II. No pleurobranch on the fourteenth somite. No epipodite on the third maxillipeds. No ventral rostral teeth.

A. A distal fixed pair of spines on the telson and one to three pairs of mobile lateral spines. Basal segment of antennular peduncle with a spine on its median border.

Parapenaeus group

AA. No distal fixed pair of spines on the telson, although mobile lateral spines may be present. No spine on median border of basal segment of antennular peduncle.

a. Exopods of walking legs absent behind tenth somite. No spines on the distomedian margins of basis or ischium of anterior legs.

Macropetasma group

aa. Exopods of walking legs present behind tenth somite. Spines present on the distomedian margins of basis or ischium of anterior legs.

Trachypenaeus group

Key to Genera of the Penaeus Group

I. Anteroinferior angle of carapace dentiform. Telson armed with three pairs of fixed spines. Telson, carapace and pleon covered by dense pubescence. External margin of uropodal exopods with strong tooth proximad the tip.

Funchalia Johnson

II. Anteroinferior angle of carapace not dentiform. Telson not armed with fixed spines but when armed, with three pairs of mobile lateral spines. Telson, carapace and pleon not covered with dense pubescence. External margin of uropodal exopods without strong tooth proximad the tip.

Penaeus Fabricius

One other genus, ***Heteropenaeus*** DeMan, consisting of possibly only one species, ***H. longimanus*** DeMan, occurs in the East Indian Archipelago. The genus is very closely allied to ***Penaeus*** and with the literature at hand separation was not possible.

Key to Species of the Genus *Funchalia* Johnson

I. Rostrum with ventral armature. Antennal angle unarmed.
Sub-genus ***Pelagopenaeus*** Burkenroad

One species, ***Funchalia (Pelagopenaeus) balboae*** (Faxon), Atlantic and Pacific.

II. Rostrum without ventral armature. Antennal angle armed.
Sub-genus ***Funchalia***

A. With hepatic tooth. Rostrum armed with 10+1 to 12+1 dorsal teeth.

a. Ridge posterior to pterygostomian spine rather short being about five times the length of the spine.
F. danae Burkenroad—"Dana" Station 4017 VII

aa. Ridge posterior to pterygostomian spine rather long being about ten times the length of the spine.
F. woodwardi Johnson—North and South Atlantic

AA. Without hepatic tooth. Rostrum armed with 5+1 to 6+1 dorsal teeth.

a. Carapace with frontal margin sloping posteriorly ventral of pterygostomian spine.
F. taaningi Burkenroad—"Dana" Station 3920 III

aa. Carapace with frontal margin sloping vertically or possibly anteriorly ventral of pterygostomian spine.
F. villosa (Bouvier)—Eastern and Western North Atlantic, South Atlantic and Caribbean

Key to Species of the Genus *Penaeus* Fabricius

I. Lateral rostral sulci not reaching almost to the posterior margin of the carapace; postocular crest absent.

A. Species limited to Atlantic America.

a. Ventral margin of pleuron of first pleonic somite almost straight. Anterolateral marginal ridges of XIV sternite of female extending conspicuously mediad near middle of segment making interrupted crescentic transverse ridge with concavity directed forward. Posterior portion of XIV sternite of female with conspicuous pair of fleshy protuberances. Posterior margin of XII sternite of female with pair of lateral convexities which extend almost level with median portion of the margin. Petasma of male with diagonal ridge across ventral face of distolateral lobe.[12]
P. setiferus (Linn)—Atlantic, North America

[12]From Burkenroad, 1936b.

aa. Ventral margin of pleuron of first pleonic somite distinctly concave. Anterolateral marginal ridges of sternite XIV of female not extending conspicuously mediad near middle of segment. Pair of longitudinal ridges on anterior part of XIV. Posterior portion of sternite XIV of female without conspicuous pair of fleshy protuberances. Posterior margin of XII sternite of female with pair of lateral convexities which project well beyond median portion of margin. Petasma of male without diagonal ridge across ventral face of distolateral lobe.[3]

P. schmitti Burkenroad—Atlantic, South America

AA. Species limited to Pacific America.

a. Posterior ventral rostral tooth directly below or in advance of anterior dorsal rostral tooth. Lateral rostral carinae extending not further than front of posterior dorsal carapacic spine. Rostral teeth generally 9/2. Thelycum of females not densely pubescent; two ventrally projecting flattened plates on the anterior portion of the sternum of somite 14. Coxae of fifth legs of female not medially produced as projecting flaps.

P. vannamei Boone

aa. One or more posterior ventral rostral teeth behind anterior dorsal rostral tooth. Lateral rostral carinae extending behind front of posterior dorsal carapacic tooth. Rostral teeth usually 8-11/3-5. Thelycum of females without two ventrally projecting plates on the anterior portion of the sternum of somite XIV.

1. Rostral teeth generally 8/4-5. Antennular flagella longer than peduncle. Males with well spaced spines on mid-dorsal surface of inferior antennular flagella. Female with prominent ventrally produced median triangular-shaped protuberance on sternum of somite XIV. Coxae of third, fourth and fifth legs of female with large medially produced flaps. Thelycum of female not densely pubescent.

P. styllirostris Stimpson

2. Rostral teeth generally 10-11/3-5. Antennular flagella equal to or shorter than peduncle. Males with close-set spines on externolateral margin of inferior antennular flagella. Females without prominent ventrally produced median triangular-shaped protuberance on sternum of somite XIV. Coxae of third, fourth and fifth legs of female not greatly produced medially. Thelycum of female densely pubescent.

P. occidentalis Streets

AAA. Species limited to Indo Pacific and East Coast of Africa.
- a. A more or less prominent subhepatic crest on the carapace.
  - 1. Fifth pair of legs without exopodites.
    - a′. Antennular flagella somewhat shorter than peduncles. Occurs in Indo Pacific around Singapore. ***P. carinatus*** Dana
    - a′a′. Antennular flagella somewhat longer than peduncles. Occurs on East Coast of South Africa at about 33° S. latitude. ***P. caeruleus*** Stebbing
  - 2. Fifth pair of legs possessing small exopodites.
    - a′. With sulcate postrostral carina. ***P. semisulcatus*** De Haan
    - a′a′. Without sulcate postrostral carina or grooves. ***P. esculentus*** Haswell
- aa. No subhepatic crest on the carapace.
  - 1. Rostral crest of moderate heighth. ***P. indicus*** H. Milne Edwards
  - 2. Rostral crest high and assuming a triangular shape. ***P. merguiensis*** DeMan
  - 3. Rostral crest high but not assuming a triangular shape. ***P. penicillatus*** Alcock

II. Lateral rostral sulci reaching almost to the posterior margin of the carapace; postocular crest present.
- A. Species limited to Mediterranean and Eastern and Western Atlantic.
  - a. Coxae of chelipeds armed. ***P. trisulcatus*** Leach—Mediterranean and Eastern Atlantic
  - aa. Coxae of chelipeds unarmed.
    - 1. Anteromedial corners of lateral plates of adult thelycum extended, meeting medially and covering completely posteriomedian part of median plate of XIII. Median carina on median plate of XIII absent. Tip of distoventral lobe of male petasma projecting. ***P. brasiliensis*** Latreille—Atlantic, North and South America, but not from Gulf of Mexico
    - 2. Anteromedial corners of lateral plates of adult thelycum not extended, not converging medially nor covering carina of posteriomedian part of median plate of XIII. Carina present on median plate of XIII. Tip of distoventral lobe of male petasma not projecting.
      - a′. External edge of distoventral lobes of male petasma armed with 2-12, usually 4-7 spinules. Carina of

posteriomedian elevation of median plate of XIII not bifurcate.

P. duoarum Burkenroad—Atlantic, North America and West Africa, also Gulf of Mexico

a′a′. Spines absent from external edge of distoventral lobe of male petasma. Carina of posteriomedian elevation of median plate of XIII bifurcate.

P. aztecus Ives—Gulf of Mexico; Atlantic, North and South America

AA. Species limited to Pacific America. Postocular crest not turning upon itself at posterior end forming more or less of a loop. Rostrum with more than one ventral tooth. Telson unarmed.

a. Carina of posterodorsal margin of antennal sulcus reaching to within not more than 3/5 its length of the orbital angle. Thelycum of female without median longitudinal carina on XIII and being cup shaped; lateral plates of XIV not meeting in the midline for their entire length, their anterior ends do not overlie and conceal the posterior elevation of XIII; ventral surface of lateral plates pubescent. In male petasma, "the medially directed distal ends of the lateral ribs terminate in a blunt tip not projecting free of the median membranes; this tip is armed on its distolateral or free edge with one or two conspicuous axially-directed teeth. . . . The proximomedian margin of the anterior, or dorsal side of the distal parts of lateral ribs bears a row of 8 to 11 spines along its juncture with the membraneous median parts of the petasma. The folded distal edge of the median parts, at the point of juncture with the tip of the lateral rib, does not project inward as a conspicuous fleshy flap, and is here unarmed."[13] Outer margin of appendix masculina of second male pleopods with pronounced curve.

P. brevirostris Kingsley

aa. Carina of posterodorsal margin of antennal sulcus reaching to within about half its length of the orbital angle. Thelycum with median longitudinal carina on XIII. "The lateral plates of XIV meet in the midline for their entire length, their anterior ends thus overlying and concealing the posterior part of the elevation of XIII."[14] Ventral surface of lateral plates not pubescent. "The medially curved distal ends (distoventral lobes) of the heavily chitinized lateral ribs of the petasma terminate in a sharply pointed recurved tip which is free from the membranes forming the median parts of the petasma";[15] proximomedian margin of the anterior, or dorsal side of the distal parts of the lateral ribs un-

[13]Burkenroad, 1938, page 71.
[14]Burkenroad, 1938, pages 70, 71.
[15]Burkenroad, 1938, page 71.

armed along its juncture with the median or membraneous parts of the petasma; the folded distal edge of the median parts, at point of juncture with the tip of the lateral rib, projecting inward as a conspicuous fleshy flap which is armed with several series of spines. Outer margins of appendix masculina of second male pleopods straight or nearly so.
P. californiensis Holmes

AAA. Species limited to Indo Pacific. Postocular crest turning upon itself at posterior end forming more or less of a loop. Rostrum with but one ventral tooth (except ***P. marginatus*** Randall). Telson armed laterally with three pairs of mobile spines (except ***P. canaliculatus*** Olivier).

a. Telson not armed with mobile spines
P. canaliculatus Olivier

aa. Telson armed with three pairs of mobile spines.

1. Ischium of first leg armed.
P. marginatus Randall

2. Ischium of first leg unarmed.

a′. "Lateral grooves on carapace paralleling medially sulcate post-rostral carina to posterior margin of carapace.

1′. Rostrum without a secondary or accessory pair of lateral rostral sulci.

a″. Thelycum tubular (oval in cross-section), the two lateral plates being indistinguishably united on the median line to form a single large plate. Petasma with submedian teeth or "horns" bent over, so as to overhang the distal margin of the side plates of the petasma.
P. japonicus, Bate

a″a″. Thelycum composed of two distinct plates, juxtaposed, but not united on the median line. Petasma with submedian teeth or protuberances but slightly bent over, and not overhanging the distal margin of the side plates of the petasma.
P. latisulcatus, Kishinouye

2′. Rostrum with a secondary pair of lateral carinae subtending an accessory pair of lateral sulci on the sides of the upper blade of the rostrum, not extending backward behind the last rostral (gastric) tooth. Thelycum and petasma much as in ***P. latisulcatus.***
P. plebejus, Hess

a′a′. Lateral grooves on carapace posteriorly confluent, uniting behind the sulcated postrostral carina and crossing over to form an X-shaped depression.
P. maccullochi, Schmitt"[16]

THE GENUS *Heteropenaeus* DEMAN

One species, ***H. longimanus*** DeMan, occurs in the East Indian Archipelago.

KEY TO GENERA OF THE PARAPENAEUS GROUP

I. Somite 13 with a small filamentose anterior arthrobranch. Exopods absent behind ninth somite. No spines on the distomedian margins of basis or ischium of anterior legs.
Artemesia Bate

II. Somite 13 without a small filamentose anterior arthrobranch. Exopods present behind ninth somite. Spines present on the distomedian margins of basis or ischium of anterior legs.
A. Carapace with longitudinal and transverse sutures present. Rudimentary arthrobranch of somite 7 without filaments.
Parapenaeus Smith

AA. Carapace without longitudinal and transverse sutures. Arthrobranch of somite 7 filamentous.
Penaeopsis Bate

THE GENUS *Artemesia* BATE

Probably only one species, ***A. longinaris*** Bate.

KEY TO SPECIES OF THE GENUS *Parapenaeus* SMITH

I. Species limited to the Atlantic.
A. Branchiostegal spine placed behind anterior margin of carapace. Rostral teeth usually 7. Epigastric and hepatic teeth not as far behind orbital margin as in ***P. americanus.***
P. longirostris (Lucas). (Occurs in Gulf of Mexico and on European and American sides of Atlantic.)

AA. Branchiostegal spine placed on anterior margin of carapace. Rostral teeth usually 6. Epigastric and hepatic teeth placed farther behind orbital margin than in *P. longirostris.*
P. americanus Rathbun. (Reported from Caribbean.)

II. Species occurring in the Indo Pacific.
A. Carapace without spine on the anteroinferior region.
P. longipes Alcock

[16]Schmitt, 1926, page 359.

AA. Carapace with spine on the anteroinferior region.

a. Branchiostegal spine placed behind anterior margin of carapace.

P. investigatoris Alcock and Anderson

aa. Branchiostegal spine placed on anterior margin of carapace.

P. fissurus Bate

KEY TO SPECIES OF THE GENUS *Penaeopsis* BATE

I. "*Penaeopsis* Bate, sensu stricto. Petasma symmetrical. Vestigial anterior arthrobranch of somite XIII absent."[17]

Sub-genus **Penaeopsis** Bate ss

A. Species limited to Atlantic.

P. megalops (Smith)

AA. Species limited to Indo Pacific.
Two species, **P. serratus** Bate and **P. rectacutus** Bate. These two species, do not appear to have been satisfactorily separated.

II. "*Metapenaeopsis* Bouvier, 1905 a, redefined. Petasma asymmetrical. Vestigial anterior arthrobranch of somite XIII present (save in **P. lamellatus** (DeHaan) according to Schmitt, 1926 a). Type, **Penaeopsis (Metapenaeopsis) pubescens** (Bouvier)."[18]

A. "External piece (distoventral projection) of the left petasmal endopod reduced to a rudiment. Known distribution limited to the Atlantic and the American Pacific."[19]

a. Species limited to the American Atlantic.

1. Adult petasma; "*P. smithi*—Right distoventral projection deeply cleft into two subequal lobes. Left endopod not extending nearly as far distad as does the right distomedian lobe. Inner part of the distolateral lobe a blunt vertical cone (not extending much above the level of the distomedian lobe) joined to the dorsolateral edge of which is a projection which does not rise above the level of the cone. Spinules are placed on the distal surface of the projection in the region where it joins the cone. At the base of the left endopod, laterad the projecting median spur, is a low rounded prominence."[20] Adult female with median plate of sternum of somite XIII containing two spiral pits.

P. (Metapenaeopsis) smithi Schmitt

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[17]Burkenroad, 1934,b, page 8.
[18]Burkenroad, 1934b, page 8.
[19]Burkenroad, 1934b, page 8.
[20]Burkenroad, 1934b, page 25.

2. Adult petasma; "*P. goodei*—Right distoventral projection less deeply cleft, the left lobe usually smaller than the right. Left endopod extending nearly as far distad as does the right distomedian lobe. Inner part of the distolateral lobe a greatly produced slender clavate projection rising far above the level of the distomedian lobe, and bearing spinules upon its distal surface. Laterad the median spur at the base of the left endopod is a long slender tooth, visible even in dorsal view."[21] Thelycum of adult female without spiral pits on median plate of somite XIII.

P. (Metapenaeopsis) goodei Smith

aa. Species limited to American Pacific.

1. Basis of second leg unarmed.

P. (Metapenaeopsis) kishinouyei (Rathbun)

2. Basis of second leg usually armed.

a′. Rostral teeth usually 9+1 or 8+1.

P. (Metapenaeopsis) beebei Burkenroad

a′a′. Rostral teeth usually 11+1 or 10+1.

P. (Metapenaeopsis) mineri Burkenroad

Burkenroad 1938 gives differences between secondary sexual organs of these three American Pacific forms.

AA. "Distolateral projection of the left petasmal endopod as large as or larger than the right one. Known distribution limited to the Indopacific. Species grouped by Kishinouye, 1929, as follows: (*Leptopenaeus*) *P. philippii* Bate [with which *P. coniger andamensis* (Wood-Mason and Alcock) and *P. philippinensis* (Bate) are synonymous, Calman, 1923], *coniger* Wood-Mason and Alcock, *sibogae* DeMan, *distinctus* DeMan. (*Ceratopenaeus*) *P. dalei* Rathbun, *mogiensis* Rathbun (with which *P. hilarulus* DeMan is synonymous, Schmitt, 1926 a), *lamellatus* DeHaan, *borradalei* DeMan. (*Erythropenaeus*) *P. acclivis* Rathbun, *barbatus* DeHaan (with which *P. akayebi* Rathbun is synonymous, DeMan, 1911). Other named Indopacific species probably of the section are: *P. assimilis* DeMan, *batei* Miers, *commensalis* Borradaile, *consobrinus* Nobili, *evermanni* Rathbun, *gallensis* Pearson, *gracilis* Dana, *longipes* Paulson, *novae-guineae* Haswell [with which *P. stridulans* (Alcock) is synonymous, Schmitt, 1926 a], *perlarum* Nobili, *quinquedentatus* DeMan, *vaillanti* Nobili, *velutinus* Dana."[22]

No attempt is made to key out these species.

[21] Burkenroad, 1934b, page 25.
[22] Burkenroad, 1934b, page 8.

The Macropetasma Group

Only one genus, ***Macropetasma*** Stebbing.

Key to Genera of the Trachypenaeus Group

I. Pleurobranch present on thirteenth somite. Exopodite absent from fifth leg only.
Metapenaeus Wood-Mason and Alcock

II. Pleurobranch absent on thirteenth somite. Exopodite not absent from fifth leg only.
A. Exopodite absent from second maxilliped. Three anterior legs with very weak chelae, having short fingers and much lengthened palm.
Protrachypene Burkenroad

AA. Exopodite present on second maxilliped. Three anterior legs not having chelae as above.
a. Dactyls of last two pereiopods elongate and subdivided.
Xiphopenaeus Smith

aa. Dactyls of last two pereiopods not elongate and subdivided.
1. Longitudinal and transverse sutures absent from carapace.
Trachypenaeopsis Burkenroad

2. Longitudinal or transverse sutures or both present on carapace.
a′. Antennal spine without buttress at its base. Spine on basis of third legs. Transverse suture present on carapace.
Atypopenaeus Alcock

a′a′. Antennal spine with buttress at its base. Spine absent from basis of third legs (except in female of ***Parapenaeopsis*** *maxillipedo* Alcock which species, however, has a longitudinal suture on carapace).
1′. Epipodites absent from third pereiopods.
Parapenaeopsis Alcock

2′. Epipodites present on third pereiopods.
Trachypeneus Alcock

Genus *Metapenaeus* Wood-Mason and Alcock

"Known species confined to the Indopacific (save for certain migrants into the Mediterranean through the Suez Canal). Type, *Metapenaeus affinis* (H. Milne Edwards). Named species: *M. affinis* H. M. Edwards, *mutatus* Lanchester, *monoceros* Fabricius, *elegans* DeMan,

incisipes Bate, ***deschampsi*** Nobili, ***cognatus*** Nobili, ***spinulicauda*** Stebbing. *M. stebbingi* Nobili. *M. dobsoni* Miers, *joyneri* Miers, *brevicornis* H. M. Edwards, *lyssianassa* DeMan. *M. macleayi* Haswell, *demani* Roux. *M. ensis* DeHaan, *intermedius* Kishinouye, *intermedius anchista* DeMan, *endeavouri* Schmitt."[23]

Inasmuch as the species comprising the genus appear to be rather badly confused, no attempt is made to devise a key.

Genus *Protrachypene* Burkenroad

One known species, ***P. precipua*** Burkenroad, from Pacific America.

Key to Species of the Genus *Xiphopenaeus* Smith

I. Species limited to Atlantic America. ***X. kroyeri*** (Heller)

II. Species limited to Pacific America. ***X. riveti*** Bouvier

Key to Species of the Genus *Trachypenaeopsis* Burkenroad

I. Species limited to Atlantic America.
One species, ***T. mobilispinis*** (Rathbun)

II. Species limited to Indo Pacific.
One species, ***T. richtersii*** (Miers)

Genus *Atypopenaeus*, Alcock

Possibly only one species, ***A. compressipes*** (Henderson), occurring in the Indo Pacific.

Key to Species of the Genus *Parapenaeopsis* Alcock

I. Epipodites present on the first and second walking legs.
  A. Chelipeds without basisal armature.
    a. Epigastric tooth not present.
      P. gracillima Nobili—Indo Pacific
    aa. Epigastric tooth present.
      P. balli Burkenroad—Pacific America
  AA. Chelipeds with basisal armature.
    a. Species limited to Eastern Atlantic.
      One species, ***P. atlantica*** Balss—Eastern Atlantic
    aa. Species limited to Indo Pacific.
      1. Second chelipeds without spine on the basis.
        P. uncta Alcock—Indo Pacific

[23]Burkenroad, 1934b, page 7.

2. Second chelipeds with spine on the basis.
   a'. Telson with conspicuous fixed lateral spines.
   P. stylifera (H. Milne Edwards)—Indo Pacific

   a'a'. Telson with three to five pairs of small mobile lateral spines.
   P. hardwickii (Miers)—Indo Pacific

   a'a'a'. Telson without lateral spines (except rarely in ***P. sculptilis***).

   1'. Postrostral carina not extending to near posterior end of carapace.
   P. nana Alcock—Indo Pacific

   2'. Postrostral carina extending to near posterior end of carapace.
   a''. Postrostral carina with sulcus.
   P. sculptilis (Heller)—Indo Pacific

   a''a''. Postrostral carina without sulcus.
   P. maxillipedo Alcock—Indo Pacific

   One other species, ***P. cornutus*** (Kishinouye), closely allied with ***maxillipedo*** may possibly be identical.

II. Epipodites absent from the first and second walking legs.
   A. Epigastric tooth present.
   a. Spine present on basis of second leg. Postrostral carina present.
   P. hungerfordi Alcock—Indo Pacific

   aa. Spine absent from basis of second leg. Postrostral carina absent.
   P. venusta DeMan—Indo Pacific

   AA. Epigastric tooth absent.
   Two species, ***P. tenellus*** (Ortmann) and ***P. acclivirostris*** Alcock. Indo Pacific.

Key to Species of the Genus *Trachypeneus* Alcock

I. First and second pairs of walking legs with epipods present.
   Sub-genus ***Trachysalambria*** Burkenroad

   A. Carapace with longitudinal suture reaching well behind the hepatic spine. Spine present on basis of third maxilliped. First legs with ischium unarmed. Species limited to Atlantic and Pacific America.

a. Species limited to Atlantic America.

1. Anterior margins of median plate of thelycum truncated. Lips of transverse groove of thelycum truncated. Ventral surfaces of thelycum naked. Sternal elevation between bases of fifth legs of male has lateral margins sloping regularly to the narrow posterior end. Exopodite of fifth leg does not reach to distal end of basis. Tip of telson usually tapers regularly to a point although some indication of proximal shoulder may be present. Shrimp colored with orange and red.
T. (Trachysalambria) similis (Smith)—Atlantic America

2. Anterior margins of median plate of thelycum convexly rounded. Lips of transverse groove of thelycum convexly rounded. Ventral surfaces of thelycum pubescent. Sternal elevation between bases of fifth legs of male with margins indented setting off posterior part of plate from broad anterior basal portion. Exopodite of fifth leg larger and longer than in *T. similis.* Base of terminal point of telson always enlarged into a broad shoulder from which slender distal part is well set off. Shrimp colored with lavender and chocolate.
T. (Trachysalambria) constrictus (Stimpson)—Atlantic America

aa. Species limited to Pacific America.

1. Third pleonic somite with tooth present at posterior end of mid-dorsal carina. Telson without lateral armature.
T. (Trachysalambria) byrdi Burkenroad

2. Third pleonic somite without tooth at posterior end of mid-dorsal carina. Telson with lateral armature.
T. (Trachysalambria) similis pacificus Burkenroad

AA. Carapace with longitudinal suture not reaching behind hepatic spine. No spine present on basis of third maxilliped. First legs with ischium armed.

a. Species limited to Pacific America.
One species, *T. (Trachysalambria) brevisuturae* Burkenroad

aa. Species limited to Indo Pacific.
One species, *T. (Trachysalambria) curvirostris* (Stimpson) *T. granulosus* (Mier) and *T. asper* Alcock are probably identical with *T. curvirostris* (Stimpson).

II. First and second pairs of walking legs without epipods. Species limited to the Indo Pacific.
Subgenus *Trachypenaeus*

Species of this subgenus do not appear to have been satisfactorily separated and no attempt is being made to key them out. The following species can probably be assigned to the subgenus: *T. anchoralis* (Bate), *T. granulosus* (Haswell), *T. salaco* DeMan, *T. pescadoreensis* Schmitt.

Sub-Family Eusicyoninae Burkenroad

The one genus only, ***Eusicyonia*** Stebbing.

I. Species occurring in Atlantic American waters.

A. "Antennal angle unarmed. Dorsal carina of the second pleonic somite notched dorsad the junction of the transverse sulci. Dorsal carina of the fifth pleonic somite not ending posteriorly in a tooth or sharp angle. Basis and ischium of the first chelipeds armed with a spine."[24]

a. Dorsal carina of carapace with three teeth behind orbital margin, middle of which is largest. Anterior tooth much smaller than posterior two and about equal to rostral teeth in size. Anterior tooth appears as part of rostral series. Rostrum with two teeth behind terminal portion; terminal portion divided into four teeth; one or two short mobile spines on ventrodistal end of rostrum.

Eusicyonia laevigata (Stimpson)—Atlantic and Pacific America

aa. Dorsal carina of carapace with three teeth behind orbital margin, all of about equal size and the anterior tooth considerably larger in size than those in rostral series. Rostrum with three teeth behind terminal portion; terminal portion divided into three teeth with rudiment of a fourth; no mobile spinules on ventrodistal end of rostrum.

Eusicyonia parri Burkenroad

AA. "Antennal angle armed with a buttressed spine. Dorsal carina of the second pleonic somite not incised. Dorsal carina of the fifth pleonic somite ending posteriorly in a tooth or sharp angle. Basis and ischium of the first chelipeds unarmed."[25]

a. "Postrostral carina with three or four teeth behind the orbital margin, of which two are large and placed far behind the orbit."[26]

Eusicyonia brevirostris (Stimpson)—Occurs in both Atlantic and Pacific America

aa. "Postrostral carina with two or three teeth behind the orbital margin, of which two are large and placed far behind the orbit."[27]

Eusicyonia edwardsi (Miers)

[24]Burkenroad, 1934b, page 71.
[25]Burkenroad, 1934b, page 73.
[26]Burkenroad, 1934b, page 73.
[27]Burkenroad, 1934b, page 73.

aaa. "Postrostral carina with two teeth behind the orbital margin, of which one is large and placed behind the level of the hepatic spine."[28]

1. Rostrum elevated at a considerable angle. Rudimentary third tooth appearing as a minute crestlike swelling slightly in advance of posterior tooth of carapacic carina, usually with a sharp truncated anterior edge. Lateral rostral ridge runs near to and parallel with ventral margin. Proximal median margin of depression of external surface of basal segment of mandibular palp convex inward.
Eusicyonia stimpsoni (Bouvier)

2. Rostrum extends horizontally or below horizontal. No trace of rudimentary third tooth on carapacic carina. Lateral rostral ridge slopes upward to near dorsal margin. Proximal median margin of depression of external surface of basal segment of mandibular palp convex outward.
Eusicyonia dorsalis (Kingsley)

II. Species occurring in Pacific American waters.

A. "Antennal angle unarmed. Dorsal carina of the second pleonic somite notched dorsad the junction of the transverse sulci. Dorsal carina of the fifth pleonic somite not extending posteriorly in a tooth or sharp angle. Basis and ischium of the first chelipeds armed with a spine."[29]

a. Dorsal carina of carapace with three teeth behind orbital margin, middle of which is largest. Anterior tooth much smaller than posterior two and about equal to rostral teeth in size. Anterior tooth appears as part of rostral series. Rostrum with two teeth behind terminal portion; terminal portion divided into four teeth. One or two short mobile spines on ventrodistal end of rostrum.
E. laevigata (Stimpson)—Atlantic and Pacific America

aa. Dorsal carina of carapace with three teeth behind orbital margin, all of about equal size and the anterior tooth considerably larger in size than those in rostral series. Rostrum with three teeth behind terminal portion; terminal point with four or five teeth; ventrodistal margin of rostrum with a mobile spinule.
E. disparri Burkenroad

AA. "Antennal angle armed with a buttressed spine. Dorsal carina of the second pleonic somite not incised. Dorsal carina of the fifth pleonic somite ending posteriorly in a tooth

[28] Burkenroad, 1934b, page 73.
[29] Burkenroad, 1934.

or sharp angle. Basis and ischium of the first chelipeds unarmed."[30]

a. "Postrostral carina with three or four teeth behind the orbital margin, of which three are large and placed far behind the orbit."[31]

E. brevirostris (Stimpson)—Atlantic and Pacific America

aa. "Postrostral carina with two or three teeth behind the orbital margin, of which two are large and placed far behind the orbit."[32]

1. Rostrum with two teeth behind the bifurcated tip (this does not include the anterior tooth of the carapace which sometimes appears forward of the orbital margin). Pair of median stylets on ocular somite divergent, with a rather conspicuous bend near the tips.

E. disedwardsi Burkenroad

2. Rostrum with one tooth behind the bifurcated tip (Burkenroad 1938 stated that about one individual in ten bears two teeth). Pair of median stylets on ocular somite bent only slightly if at all.

E. penicillata (Lockington)

AAA. "Postrostral carina with two teeth behind the orbital margin, of which one is large and placed behind the level of the hepatic spine."[33]

a. Posterior tooth of carapace very large and placed very near to posterior margin of carapace to which it slopes as a high carina.

1. First pleonic somite with shallow anteromedian pleural sulcus reaching only about one-fourth the distance from point of origin to ventral edge. Pleonic surface smooth, although it is punctate and setose.

E. affinis (Faxon)

2. First pleonic somite with deep anteromedian pleural sulcus reaching close to ventral margin and meeting posteromedian pleural sulcus. Pleonic surface tuberculate and somewhat wrinkled.

E. alliaffinis Burkenroad

aa. Posterior tooth of carapace larger than anterior tooth but not extremely so and placed well in advance of posterior margin of carapace.

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[30]Burkenroad, 1934b, page 73.
[31]Burkenroad, 1934b, page 73.
[32]Burkenroad, 1934b, page 73.
[33]Burkenroad, 1934b, page 73.

1. Dorsal carina posterior to last tooth of carapace a high crest. Rostrum with four teeth and a trifurcate tip. Rostrum elevated at a considerable angle.
   E. picta (Faxon)

2. Dorsal carina posterior to the last tooth of carapace, although clearly marked is low. Rostrum with three teeth and a bifurcate tip. Rostrum extends almost horizontally to below horizontal with a decurved tip.
   a′. Telson armed with a conspicuous pair of fixed lateral spines. Telson exceeding uropods. Rostrum with lateral ridge paralleling ventral margin for its entire length.
   E. ingentis Burkenroad

   a′a′. Telson armed with a very small inconspicuous pair of fixed lateral spines. Telson shorter than uropods. Rostrum with lateral ridge arching up from ventral margin close to the distal end.
   E. disdorsalis Burkenroad

III. Species occurring in Eastern Atlantic and Mediterranean. One species, ***E. carinata*** (Olivier).

IV. Species occurring in the Indo Pacific.

E. benthophila (DeHaan) | ***E. fallax*** (DeMan)
E. ocellata (Stimpson) | ***E. trispinosa*** (DeMan)
E. rectirostris (DeMan) | ***E. bispinosa*** (DeHaan)
E. parvula (DeHaan) | ***E. cristata*** (DeHaan)
E. laevis (Bate) | ***E. furcata*** (Miers)
E. curvirostris (Balss) | ***E. japonicus*** (Balss)
E. lancifer (Olivier)

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HOW TO MARK FISH

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ABSTRACT

The records of the tagging of 462,000 marine and anadromous fishes from 1873 to 1933 are summarized by species and locality. An effort has been made to clear up the confusion in the names and descriptions of tags by classifying all the tags actually used into 18 categories which are defined. An illustration is given of one or more tags in each category. The origin, use, and development is discussed for each tag, accompanied by an accurate description of size, shape and material. How to plan a tagging experiment so as to yield the type of information desired is discussed at length. Methods are given for recovering tags from the liberated fish by advertising, canvassing, direct observation, payment of rewards and mechanical sorters. The need for the use of proper field methods is stressed in experiments designed to show the relative efficiency of different tags. Drawing to a large extent on personal experience the actual field technique employed is discussed at length. A bibliography of 232 references contains all the important papers on tagging to within recent years and provides the basis for the tabulations of numbers and species of fish tagged, and gives the original description of each tag.

INTRODUCTION

A study of tagging is rendered difficult by the inexactness with which experiments have been described, and by the human trait of high-lighting a success but neglecting to mention a failure. This has often led to the repetition of poor techniques. Because tagging is usually a cold and disagreeable job, the biologist has been too prone to shirk the task and throw onto the shoulders of assistants the work that counts the most in any tagging experiment.

The authors of this paper have found from their own experience the lack of organized knowledge on tagging. The senior author was formerly in charge of the Alaska herring investigations, including tagging, and later in charge of haddock tagging and salmon marking in the North Atlantic for the Fish and Wildlife Service, United States Department of the Interior. The junior author was formerly in charge of halibut tagging for the International Fisheries Commission (United States and Canada) and later in charge of salmon tagging for the International Pacific Salmon Commission (United States and Canada).

The present contribution is written with the hope that it may spare many investigators from repeating the mistakes of the past and may suggest the adoption of better technique in the future.

TABLE 1.—*Numbers of fish tagged by species and by years, 1873-1933*

Species	1873-91	1892-94	1895-97	1898-00	1901-03	1904-06	1907-09	1910-12	1913-15	1916-18	1919-21	1922-24	1925-27	1928-30	1931-33	Total
Salmon & Sea Trout:																
Salmo[1]	4,954	4,542	2,306	785	3,827	4,600	1,620	1,847	4,606	2,342	3,943	3,876	4,303	5,971	6,086	55,60
Oncorhynchus[2]	......	......	......	......	......	......	41	......	......	4,494	......	18,970	36,683	20,851	467	81,50
Flatfishes:																
European plaice	1,250	396	......	......	5,731	31,953	17,731	11,764	2,232	......	4,625	1,661	6,849	12,711	16,021	112,92
Halibut	......	......	......	......	......	2	2	......	......	......	......	......	10,907	1,029	192	12,13
Other flatfish	56	......	......	......	110	2,351	234	394	203	......	1,181	2,026	2,235	5,394	4,783	18,96
Round bankfishes:																
Codfish	......	......	562	3,457	......	1,380	1,976	3,740	4,665	......	163	15,724	36,311	10,664	6,236	84,87
Haddock	......	......	......	......	......	......	1	......	......	......	......	3,634	10,816	4,505	1,331	20,28
Pollock or saithe	......	......	......	......	......	......	......	......	......	......	2,119	3,131	1,401	437	450	7,53
Hake	......	......	......	......	......	......	......	......	......	......	......	......	......	......	944	94
Mackerel-like fishes:																
Mackerel																
Japanese	......	......	......	......	......	......	......	......	......	......	200	1,336	4,924	3,839	......	10,29
W. Atlantic	......	......	......	......	......	......	......	......	......	......	......	......	10,408	3,526	......	13,93
Black Sea	......	......	......	......	......	......	......	......	......	......	......	......	......	......	3,270	3,27
Tuna	......	......	......	......	......	......	......	10	......	......	......	......	......	......	126	13
Yellowtail	......	......	......	......	......	......	......	......	......	63	91	256	725	763	......	1,89
Swordfish	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1	
Herring	......	600	......	......	......	......	......	......	......	......	......	......	3,071	......	10,028	13,69
Shorefishes:																
Mullet	......	......	......	......	......	......	......	......	......	......	......	......	6,000	......	......	6,00
Squeteague	......	......	......	......	......	......	......	......	......	......	......	......	......	1,800	7,313	9,11
Scup	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5,228	5,22
Croaker	......	......	......	......	......	......	......	......	......	......	......	......	......	......	300	30
Striped bass	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1,000	1,00
Skates and rays	94	......	......	......	......	......	......	......	......	......	......	......	305	300	306	1,00
Miscellaneous	......	......	......	......	......	......	2	......	......	......	......	......	14	318	652	98
Total	6,354	5,538	2,868	4,242	9,668	40,286	21,607	17,755	11,706	6,899	12,322	50,614	134,952	72,108	64,734	461,65
Cumulative Total	6,354	11,892	14,760	19,002	28,670	68,956	90,563	108,318	120,024	126,923	139,245	189,859	324,811	396,919	461,653	......

Note: When an experiment gave the number of fish tagged over two or more years without giving the numbers marked in each individual year, then the total numb marked was distributed equally amongst the years.

[1]*Salmo* includes the European salmon and sea trout and the Pacific coast steelhead.

[2]*Oncorhynchus* includes only the five species of Pacific salmon.

Development of Tagging

The early tagging of fish was indulged in chiefly as a hobby by wealthy owners of riparian rights. Records of their tagging are very scattered and unsatisfactory. Therefore, we have commenced with the first really successful tagging experiment by Charles G. Atkins of the U. S. Fish Commission on Atlantic salmon at Bucksport, Maine, in 1873. Since tagging experiments are usually a few years old before the results are given in the literature, we do not feel that our information is complete after 1933. (Table 1.) In the 61 years from 1873 to 1933 we have records (some unpublished) of the tagging of 461,653 marine and anadromous fish. From 1934 to 1937 incomplete records give us 210,607 for a grand total of 672,260.

In the 64-year period from 1873 to 1936, out of 606,840 fish tagged, only 3 per cent were tagged before the turn of the century. The tagging of over 69,000 European plaice in the next 18 years swelled the total to 126,000 or 20.8 per cent of the total. The World War put a stop to all tagging except salmon in Canada and the United States. The last 15 years, 1922-36, thus account for 79.2 per cent of the total. Nearly one-third of this in the last 3 years of the period.

The tagging of fish, then, although it has covered a long period, has just come into its own as a highly useful tool in the hands of the conservationist. It will be noted in this connection (Table 2) that tagging has so far been concentrated in certain areas. To the end of 1933, 41.6 per cent were tagged in European waters, 32.0 per cent on the Atlantic

Table 2.—*Numbers of fish tagged by species and by waters, 1873-1933*

Species	Waters					Total
	European	Western Atlantic	Eastern Pacific	Western Pacific	South African	
Salmon & Sea Trout:						
Salmo	40,194	13,685	1,729	....	....	55,608
Oncorhynchus	....	....	81,506	....	....	81,506
Flatfishes:						
European plaice	112,924	....	....	....	....	112,924
Halibut	299	....	11,833	....	....	12,132
Other flatfish	14,788	4,179	....	....	....	18,967
Round Bankfishes:						
Codfish	14,495	70,383	....	....	....	84,878
Haddock	781	19,506	....	....	....	20,287
Pollock or saithe	2,569	4,969	....	....	....	7,538
Hake	944	....	....	....	....	944
Mackerel-like fishes:						
Mackerel	3,270	13,934	....	10,299	....	27,503
Tuna	82	....	....	....	54	136
Yellowtail	....	....	....	1,898	....	1,898
Swordfish	1	....	....	....	....	1
Herring	600	....	13,099	....	....	13,699
Shorefishes:						
Mullet	....	6,000	....	....	....	6,000
Squeteague	....	9,113	....	....	....	9,113
Scup	....	5,228	....	....	....	5,228
Croakers	....	300	....	....	....	300
Striped Bass	....	305	695	....	....	1,000
Skates and rays	1,005	....	....	....	....	1,005
Miscellaneous	40	14	....	....	932	986
Total	191,992	147,616	108,862	12,197	986	461,653
Per cent	41.6	32.0	23.6	2.6	0.2	100.0

coast of Canada and the United States, 23.6 per cent on the Pacific coast from California to Alaska, leaving but 2.6 per cent by Japan and Korea, and 0.2 per cent by South Africa.

Research, especially on the high seas, has been international in scope, so no attempt has been made to show the numbers tagged by each country. Nor is it possible to show accurately in most cases, the numbers tagged with each type of mark, as in far too many experiments the tag used is not mentioned.

Definitions of Types of Tags

ARCHER
A plate (or double plate) attached by two points or wires, one at each end, that pierce through the tissues, and then are clinched or twisted. (Nos. 1 to 5, fig. 1)

ATKINS
A loose plate (or bead) attached by a wire or thread that pierces the tissues. (Nos. 6 to 12, fig. 1)

BACHELOR BUTTON
Two discs or plates attached by a rigid shaft that pierces the tissues. (Nos. 13 to 16, fig. 1)

BARB
Any straight shaft, with or without an attached plate, that is pushed into the tissues and depends for holding wholly on a barb or barbs. (No. 18, fig. 1)

BODY CAVITY
Any material inserted loose into the body cavity. (Nos. 19 to 23, fig. 2)

COLLAR
A ring of any material (with or without an attached plate) that is held wholly by encirclement without piercing any tissues. (Nos. 24 to 28, fig. 2)

HEINCKE RING
A tag used by Heincke, that pierced the tissues and depended entirely on the spring of the metal and friction to hold. (No. 17, fig. 1)

HEINCKE STUD
A tag used by Heincke in which the shaft was rigidly attached to one disc. The other disc (of rubber) was held wholly by the knob on the end of the shaft. (No. 38, fig. 3)

HOOK
A shaft piercing the tissues and held both by the curve of the shaft and a barb or barbs. (No. 29, fig. 2)

INTERNAL ANCHOR

A flexible chain or thread (with or without any attached material on the outside) that pierces the body wall and is held by being attached to material inside the body cavity. (Nos. 49 and 50, fig. 3)

LOFTING

Two discs or plates attached by a wire or shaft piercing the tissues, with one disc loose, the other rigidly attached to the wire or shaft. (No. 41, fig. 3)

OPERCLE CLIP

A single disc or plate attached rigidly at one point to two wires or shafts that pierce the tissues and are then spread apart. (No. 30, fig. 2)

PETERSEN

Two discs or plates (sometimes double) that are attached loosely by a pin or wire that pierces the tissues. (Nos. 34 to 37, fig. 3)

RING

A ring of rigid material that pierces the tissues. The ends are not fastened together, the tag holding because of its shape. (No. 42, fig. 3)

ROUND NORWAY

Two discs connected with a wire that pierces the tissues between the discs and then makes a complete circle so that the ends are fastened together. (No. 39, fig. 3)

SAFETY PIN

Bent pin or wire (a portion may be flattened or it may carry a plate) attached by one point piercing the tissues and being held by springing against a groove or in a loop of the other. (Nos. 31 to 33, fig. 2)

STRAP

A flat metal strip (with or without an attached disc or plate), with one end piercing the tissues and clinched through a hole in the other end. (Nos. 43 to 48, fig. 3)

STURGEON

Two discs, each bearing two holes and attached by a wire that pierces the tissues in two places, making a complete circle. This tag is very similar to the Archer type. (No. 40, fig. 3)

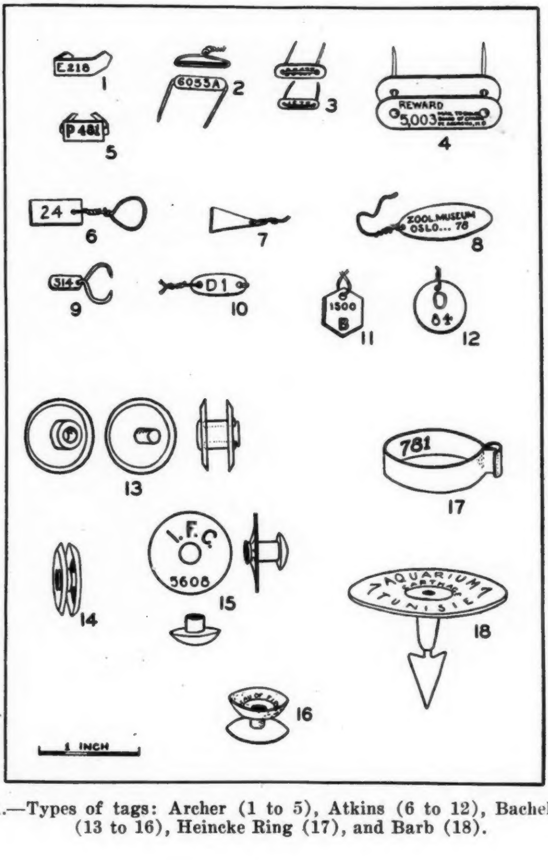

FIGURE 1.—Types of tags: Archer (1 to 5), Atkins (6 to 12), Bachelor Button (13 to 16), Heincke Ring (17), and Barb (18).

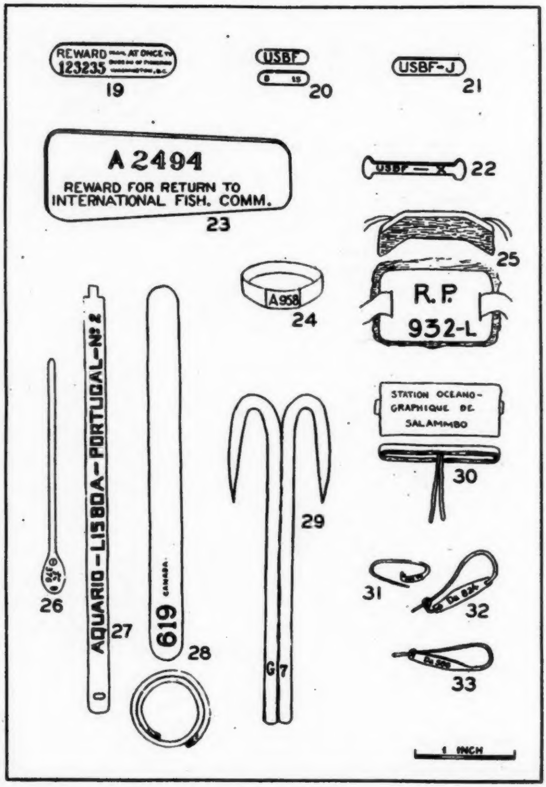

FIGURE 2.—Types of tags: Body Cavity (19 to 23), Collar (24 to 28), Hook (29), Opercle Clip (30), and Safety Pin (31 to 33).

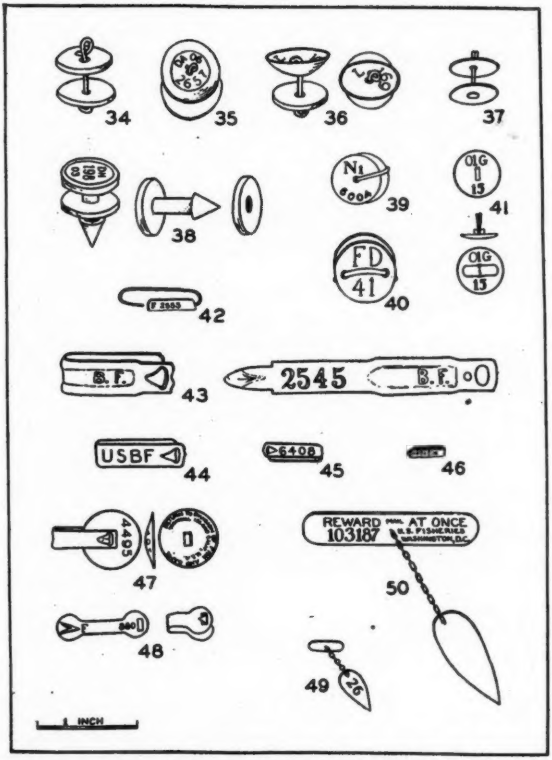

FIGURE 3.—Types of tags: Petersen (34 to 37), Heincke Stud (38), Round Norway (39), Sturgeon (40), Løfting (41), Ring (42), Strap (43 to 48), and Internal Anchor (49 and 50).

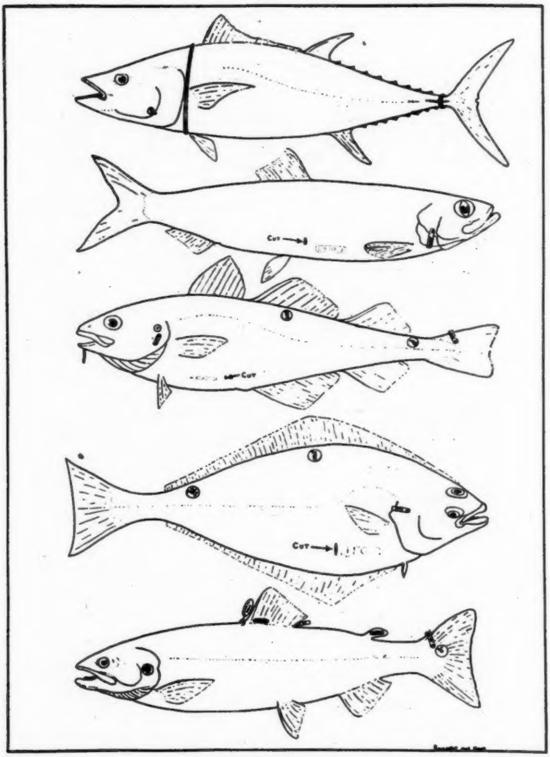

FIGURE 4.—Five types of fishes showing common placement of principal types of tags used on each. Top: Tuna (mackerel-like fish) has Strap (47) on opercle, Collar (24) encircles the body, and Collar (28) around caudal peduncle. Second: Herring (clupeoid fishes) has Fingerling Strap (46) and Body Cavity (21). Third: Cod (round bank-fishes) has Strap (44) on caudal fin, Petersen type tags on opercle, back and peduncle, a modified Archer (similar to 4) on opercle and Body Cavity (19). Fourth: Halibut (flatfishes) has Strap on opercle, Body Cavity (23), Peterson on the back and Heincke Stud near peduncle. Bottom: Salmon (salmonid fishes) bearing Løfting on opercle, Strap and Bachelor Button (13) on caudal fin, Archer on dorsal and adipose fins and Atkins anterior and posterior to dorsal fin.

Discussion of Types of Tags

ARCHER

The Archer tag was devised by William E. Archer, and first used (No. 1) on Atlantic salmon in the Sands River, Norway. The first year, 1888, the tag used was a flat strip of silver 0.2 mm. thick and 4 mm. wide. The strip was 26 mm. in total length, with the last 8 mm. on each end bent at right angles and pointed. It was attached by passing the pointed ends through the dorsal fin and then pressing them tightly to it on the opposite side. The tag was too thin, and he finally had to bind the ends together by a silver thread. In 1890 he used silver 0.4 mm. thick to correct this. In 1891 he increased the pointed ends from 8 mm. to 10 mm. in length, as 8 mm. was too short for the larger salmon. Out of 329 marked, Archer had 15 recoveries, or 4.5 per cent. Landmark tagged 6,708 salmon in Norwegian rivers with Archer marks from 1893 to 1895, and had 43 recoveries, or 2.47 per cent.

The original Archer tag was later modified somewhat. The No. 2 Archer (after Calderwood, 1902) was first used by Archer in Scotland, in 1896. About 1900 Calderwood not only soldered the plate to the wire, but also passed the wire through two holes in the plate (No. 3).

Holt, in 1901, commenced soldering a plate to each side of the wire so that the number could be read and the salmon returned to the water without removing the tag.

The silver Archer tag used in Canada (1913 on) is somewhat larger, 20 mm. long by 6 mm. wide, and two wires are used, each being soldered independently, to the inside of the plate near the end.

Commencing in 1937, Dr. A. G. Huntsman of the Fisheries Research Board of Canada, has been using an Archer tag (No. 4) of two pieces of red celluloid, each 31 mm. by 8 mm. by 0.6 mm. One piece is used on each side of the dorsal fin and they are held together by two nickel pins 1¼" (32 mm.) in length of No. 20 B. & S. gauge (.032", about 0.9 mm.) with a head of .080" in diameter.

Russell (1932) shows a similar Archer tag (except for the pins) classed as a haddock tag and used by the Fishery Board of Scotland. The wire and first plate are of silver. The second plate is of ebonite, vulcanite, or red celluloid.

The No. 5 Archer (after Russell, 1932) is shown as a tag used by Poland, on flatfish. The main plate is 10.0 mm. by 5 mm.

The Archer tag has been used by many on the adipose fin. Opinions vary as to its use on the adipose in comparison with the dorsal. Menzies (1937), in a salmon-marking experiment in Scotland, thought the Atkins (No. 8 type) and the strap tag on the caudal peduncle both superior to the Archer tag (which he used on the adipose).

ATKINS

The Atkins tag (No. 6) was used by Charles G. Atkins in 1873, on Atlantic salmon at Bucksport, Maine. He attached the tag by piercing the thin membrane of the dorsal fin, between the last and next to the last ray, by means of a needle, into the eye of which was threaded the wire, already attached to the tag. He used platinum wire and an aluminum plate ½" by ¼". The aluminum corroded, so in 1875 he used platinum for both wire and plate.

Dr. Hugh M. Smith used this tag with copper wire and a copper plate 5/16 to ¾" by ¼" on 4,019 cod at Woods Hole, Massachusetts, 1897 to 1901. He attached them to the bases of the three dorsal fins, the two anal fins, and the upper and lower caudal lobes, and obtained the best results from the upper caudal lobe. In 1897, 150 of these cod were marked with plates made of block tin, but only one was recovered and the plate was almost entirely eroded by the salt water.

From 1913 to 1916 the Canadian Fisheries Department used an Atkins tag attached to the second dorsal ray of Atlantic salmon. The plate was brass, fastened with a silk thread, and it proved worthless.

The triangular Atkins tag (No. 7) was used by William E. Archer in the Sands River, Norway, on Atlantic salmon, in 1885. The plate and wire were of platinum and the tag was attached to the adipose fin. Out of 213 marked, only two were recaptured, one without the plate.

The oblong Atkins tag (Type No. 8), also known as the Norway tag, was first tried by Archer on Atlantic salmon in 1886. It was 11 mm. long by 5 mm. wide and 0.1 mm. thick, of silver, with a double silver thread 0.25 mm. thick. He attached it to the adipose fin and recovered 9 (2 without the plate) out of 178 liberated. The tag figured (No. 8) was used in Norway in 1935 (Dahl and Somme, 1936) and is of silver 24 mm. by 9 mm., with soft silver wire. A free end of 8 cm. is left for attaching it to the back at the front of the dorsal fin. This tag gave good results.

The Atkins tag No. 9, also known as the Hillas tag (after Menzies, 1937), was invented by Hillas for use on Atlantic salmon in Ireland. The very heavy wire was clamped onto the front of the dorsal fin with special pliers. It has proved to be of very little value.

The remainder of the Atkins tags show (Nos. 10, 11 and 12) are variations figured by Russell (1932).

BACHELOR BUTTON

The bachelor button (No. 13) was first employed on 59 Pacific salmon in the Columbia River, Oregon, by Charles W. Greene, 1908. The discs are 19 mm. by 1 mm. The solid shaft is 4 mm. by 9 mm. The hollow shaft is 7 mm. by 7 mm. The tag was aluminum, weighing 2.6 grams, and attached to the upper lobe of the caudal fin. The same type in both silver (No. 14) and aluminum (No. 13), were

used by O'Malley and Rich in 1918 on 4,494 sockeye salmon in Puget Sound, Washington. The aluminum tags in this experiment did not show any corrosion, and 28.8 per cent were recaptured, which compares favorably with the same type of experiment using strap tags. Only 16.9 per cent of the silver tags (No. 14) were retaken.

The bachelor button tags Nos. 14 and 15, (drawn actual size from the tags) were used in 1925 by the International Fisheries Commission, on halibut in British Columbia, and were attached to the opercle. The No. 14 tags were some remaining from the previous salmon tagging. The concave cutting edges cut off the circulation, killing the flesh, and many halibut were retaken with a hole in the opercle where the tag had fallen out. The No. 15 tags were of monel metal. Both long and short rivets were used, but in neither case was the tag a success.

Bachelor button No. 16 was devised by William C. Herrington, for use on haddock. It was first used in 1932, attached to the left opercle. The inner portion is a red celluloid disc very slightly concave, 15.5 mm. in diameter and 0.7 mm. in thickness, with a central hole about 3.5 mm. in diameter. The outer disc which also forms a shaft is made of aluminum, which in most cases is covered with a red lacquer. This outer disc is 15.7 mm. in diameter, 0.5 mm. in thickness, and is cupped 3 mm., outside measurement. The shaft is hollow and the outside diameter tapers from 5.0 to 4.5 mm., to a shoulder. Beyond the shoulder, the shaft is 3.3 mm. in diameter to fit through the hole in the celluloid disc. This narrow portion of the disc is 1.5 mm. in length, so that the end may be riveted to the disc. For larger fish, the shaft from the bottom of the aluminum disc to the shoulder is 3.5 mm. in length, while on tags for smaller fish it is 2.3 mm. An experiment in Maine during 1938 using this tag in comparison with the No. 37 Petersen disc and the No. 50 internal anchor, shows no statistically significant differences in the number of recoveries. Although the aluminum disc is cupped outward to prevent overgrowth. it is found that within a year these tags may become almost completely covered by opercular tissue.

BARB

The barb tag (Heldt, 1932) was used in Tunis, to mark one swordfish and one tuna. (No. 18, fig. 1)

BODY CAVITY

The body cavity or "belly" tag was devised by Robert A. Nesbit, in 1931, to mark squeteague in Chesapeake Bay and was the greatest forward step in tagging since the Petersen tag. It consisted of a strip of red celluloid, about 0.7 mm. thick, that was usually about 1⅝ by ¼ inches. Later, he changed the shape to make it proportionately wider (No. 19). This tag is inserted into the body cavity by making a small vertical incision in the body wall with a scalpel. Some prefer

a scalpel with a narrow square-faced point, but more generally an arrow-headed scalpel with two sloping, cutting faces is used. The wedge-shaped halibut modification (No. 23) was devised in 1935, by John L. Kask, and is made of red celluloid about 1.5 mm. thick.

The magnetic body cavity tag (No. 20) was devised by George A. Rounsefell and Edwin H. Dahlgren and first used in 1932 on herring in Alaska. It was made of pure nickel and the tags were recovered from the herring meal in the reduction plants as the meal was being manufactured, by means of strong electro-magnets. This tag measured 13 mm. by 3 mm. by 0.7 mm.

The magnetic tag (No. 21) was modified by Rounsefell and Dahlgren in 1934, to a size measuring 19 mm. by 4 mm. by 1.0 mm. These were made of steel. Most of them were nickel-plated, but it was found that even when not plated, they did not corrode in the body cavity.

In 1935, Dahlgren also used the "dumbbell" shaped tags (No. 22) measuring 26 mm. in length, 1.0 mm. in thickness and with a shank 2.8 mm. in width and 20 mm. in length (with bulbous ends 5.4 mm. in width). This increased length was to aid in their recovery by the electric tag recovery apparatus. The bulbous ends were to aid in preventing the tags from working out of the fish through the body wall. This type did not prove any better than the No. 21.

In 1935, with the aid of the University of Washington Electrical Engineering Faculty, Dahlgren developed an electronic tag-detector, so that the fish bearing tags could be recovered as they were unloaded from the fishing vessels, instead of after their manufacture into fish meal.

In 1937 Dahlgren tried No. 21 tags of both 0.5 mm. and 2.0 mm. in thickness and found the 2.0 mm. tags to be more successful. They have the advantage of an increased weight of metal which aids the recovery apparatus and their increased crosssection may help to prevent them from working out of the fish.

These magnetic tags and the methods of recovery have now been adopted for use in tagging pilchards in British Columbia, Washington, Oregon and California and for tagging mackerel in California.

In 1937 George B. Kelez used variously colored celluloid body cavity tags of the No. 20 size to mark young coho salmon migrants in a stream emptying into Puget Sound, Washington. These tags were successfully used on young salmon only four times as long as the tag. It is the only tag so far successfully used to mark very small fish with much hope of recovery of the tags in the adult, after a tremendous increase in size, with the possible exception of the internal anchor.

COLLAR

In 1872, Charles G. Atkins tagged Atlantic salmon at Bucksport, Maine, by means of a rubber band encircling the tail and bearing an aluminum plate, but none of the fish were recovered.

In 1911, Sella tagged 10 tuna in the Mediterranean Sea with a copper chain bearing a copper plate, encircling the caudal peduncle, but none were recaptured.

From 1917 to 1922, H. Marukawa and T. Kamiya marked 174 yellwo-tail (*Seriola quinqueradiata*) in Japan with rubber bands around the tail (No. 24, fig. 2) and had 5 recoveries. In 1920, they used the same mark on 200 Japanese mackerel, but put the band around the body posterior to the gill openings. They merely state that there was no satisfactory result. Netchaeff tried the rubber band around the body on 3,270 mackerel in the Black Sea in 1933, and reported 228 recaptures.

From 1923 to 1929, Marukawa and Kamiya marked about 2,000 yellow-tail and over 10,000 mackerel with a thin strip of silver (No. 26) wound around the tail. Recaptures amounted to 9.0 per cent for yellow-tail and 0.7 per cent for mackerel.

In 1925, Oscar E. Sette commenced tagging mackerel in the North Atlantic with the celluloid poultry leg band (No. 28) around the tail. Although several thousand were marked, both in the United States and Canada, recaptures were usually under 2 per cent. A few were retaken after a long period at sea (some were out 3 years), but in most cases the fish were severely emaciated and the skin of the caudal peduncle was badly chafed.

In 1932, Portugese investigators marked tuna with a silver plate and a leather collar (No. 25) and also by a red copper strip (No. 27). Both were used on the caudal peduncle and neither type resulted in any recaptures.

HEINCKE RING

This was used by Fr. Heincke from 1902-04, to mark 1,766 European plaice (No. 17, fig. 1). Only 8.8 per cent were recovered, the poorest percentage for any of the plaice marks. The tag was of aluminum, 20 mm. by 6 mm. by 0.75 mm. thick, weighing 0.58 to 0.86 gms., adapted from a poultry leg band and was attached through the flesh near the posterior end of the dorsal fin.

HEINCKE STUD

This tag was devised by Fr. Heincke and used from 1903 to 1911 on over 27,000 European plaice, (No. 38, fig. 3). The average recovery was 20.8 per cent, which is poorer than for the Petersen types. The main portion of the tag was of ebonite, the base was 15 mm. in diameter, the shaft was 4 mm. in diameter and 10 mm. in height. The head was 7 mm. in height from its point to its base and 7 mm. in diameter at the base. The ring that slipped over the head was originally hard black rubber. Later, soft red rubber was also used and was preferred by Farran.

HOOK

This is not strictly a tag but a method of marking commercial fishing hooks, so that when a fish breaks away with a hook anyone recapturing the fish can tell in what locality and in what year the fish acquired the hook. Heldt (No. 29, fig. 2) shows a double tuna hook used by the French fisherman on the Island of Groix, stamped with a G and a 7 for the year 1927 when he commenced this system. Frade and Dentinho (1935) commenced marking hooks and distributing them to the Portugese fisherman. They were single barbed hooks of two sizes 6.5 and 8.5 cms. in height.

INTERNAL ANCHOR

This tag was recently developed by George A. Rounsefell, to meet the need for an externally visible tag in which the wound could heal quite completely and the fish could undergo a very large increase in size without losing the tag. The idea was furnished by John L. Kask, who in 1930 tried a metal tag in the body cavity, with a protruding chain, on a few flounders in a live car, and found that the wound healed completely. The internal anchor (No. 49, fig. 3) was tried in 1937, on young sockeye salmon 2 to 6 inches in length, held in tanks. The wound healed within a few days, but after nine months the experiment had to be terminated. In 1938, 100 haddock were tagged and released in Maine with a large-sized internal anchor tag (No. 50). There has been no statistically significant differences in returns between this tag and either the bachelor button or the improved Petersen tag, from haddock tagged in the same experiment.

LØFTING

This mark was devised by Løfting in 1901 and used until 1912, on Atlantic salmon in the Gudenaa River, Denmark (No. 41, fig. 3). It consists of two silver discs, 10 mm. and 12 mm. in diameter. The smaller disc carries in the center a cylindrical shaft 3 mm. high, on which are soldered two flat arms. The larger disc has an oblong hole in the center. In use, a hole is punched through the gill cover, and the smaller disc placed inside the gill cover, with its central shaft projecting through the gill cover and through the hole in the larger disc. The two discs are fastened by pressing the two arms down on the outer disc. The outer disc is slightly convex and is used with the convex side toward the gill cover. For smaller fish, discs of 8 and 9 mm. are used. This mark differs from both the Petersen type in which both discs are free, and from the Bachelor Button type in which both discs are fastened rigidly to the shaft, in that one disc is rigid on the shaft and the other is not. This tag gave poor results on salmon.

OPERCLE CLIP

The opercle clip (after Heldt, 1932) was used by Heldt in 1932 to mark tuna in Tunis (No. 30, fig. 2). He says it is made of silver

or aluminum, but does not specify which was used or how many fish were tagged. The size shown is merely a guess from Heldt's figure. This tag appears to have no desirable features.

PETERSEN

This type of tag is perhaps the most widely used and the most generally successful of all those in present use. It was invented by Petersen in 1894 (No. 34, fig. 3) for use on the European plaice in Denmark, and at first consisted of 2 bone discs connected by a silver wire twisted at either end. The tag is used on various parts of the fish, such as the nape, the back under the dorsal fin, the caudal peduncle, and the opercle. The wire pierces the tissues and each end goes through a disc and is twisted. The bone discs were not satisfactory, as the numbers that were burned into the bone soon became obliterated and the bone discs themselves gradually rotted in sea water. Various devices were used to prevent this, such as using one bone and one brass disc, or 2 bone discs with one extra brass disc on the outside, or using a brass disc set into one of the bone discs to bear the numbers (No. 35). In some cases, 4 discs were used, 2 bone discs next to the tissues, and a brass disc over each bone disc. Garstang in 1902 (No. 36) used a white bone disc on the underside and an oval, concave brass disc on the upper side in tagging plaice in England. The concavity of the brass disc was to prevent the tissues from growing over the tag, as sometimes happens when the fish are out for any length of time.

Hjort (1914) used a Petersen tag on the opercle of large cod marked in Norway in 1913, which consisted of two silver discs and a silver pin, fastened with the head of the pin toward the inside.

As early as 1905, ebonite was often being substituted for bone, the tag having one ebonite disc and one brass disc. Within a few years it was common practice to use two ebonite discs. This tag, widely used for cod and plaice, is often known as the Scottish plaice label, and has proved more successful than those using discs of bone or brass. Later, celluloid was tried in place of the ebonite and found to be equally satisfactory.

Because Petersen tags are so commonly used in European marking, there are few really detailed descriptions. Belloc (1935) states that those most frequently used in France and England have discs varying from 6.5 to 16.5 mm. in diameter.

Robert A. Nesbit, in 1930, developed a modification of the Petersen tag (No. 37) which has been used on striped bass, flounders, scup, squeteague, cod, haddock, shad, etc., on the western Atlantic coast, and on striped bass and salmon in the eastern Pacific. It consisted of using pure nickel pins instead of silver wire, printing of return instructions on the celluloid discs and in using discs small in diameter (12.5 mm.) and reduced in thickness (0.6 mm.). The usual procedure is to use one disc of white celluloid and one of red celluloid. When tagging on the opercle the red disc is usually put outside, although the

two are sometimes reversed on fish in which the white would seem to be more conspicuous.

In marking sockeye salmon in British Columbia, John L. Kask used the No. 37 tag with a white disc 13.5 mm. in diameter in the center of which is a red bull's-eye 7.5 mm. in diameter, to render the tag conspicuous while the fish is in the river on the spawning beds.

RING

A silver ring fastened through the adipose fin was used by William E. Archer in 1884, to mark 10 Atlantic salmon in the Sands River, Norway. None were recaptured. In 1898, Løfting used a horseshoe-shaped ring on Atlantic salmon clamped on the first ray of the dorsal fin, but from its abandonment, it is safe to conclude that it was not successful. The ring illustrated (No. 42, fig. 3) is after Russell (1932).

ROUND NORWAY

This type (No. 39, fig. 3) is after Russell (1932), for use on cod in Norway. The design has no features to recommend it.

SAFETY PIN

Farran (1909) describes the use of an aluminum safety pin bearing an aluminum plate used in 1905-06 on 197 plaice in Ireland. The point pierced about 1.5 cm. of skin on the back of the plaice and was then sprung into a groove on the opposite side, which was thereupon pinched together with pliers. The experiment yielded 44 recoveries.

The No. 31 safety pin (after Johansen and Løfting, 1919) was described as being used on young sea trout, fixed on the body in front of the dorsal fin.

Safety pins No. 32 and 33 are after Russell (1932). The safety pin tag has never been proved a success.

STRAP

The strap tag (No. 43, fig. 3) adapted from the cattle ear tag, was first used by Charles H. Gilbert in tagging sockeye salmon in Alaska, and was made of pure aluminum, measuring 69 mm. overall when stretched out, 9.5 mm. at the widest point and about 1.4 mm. in thickness, except for a thinner portion in the center of the strip. The original No. 43 tag had only one hole for clinching (the second small hole in the figure of the No. 43 tag was not really introduced until a few years later). The strap tag is still widely used for salmon tagging on the Pacific coast. The tags are clinched with special pliers onto the upper lobe of the caudal fin. In British Columbia, investigators mention occasionally fastening strap tags on the front of the dorsal fin of king salmon in which the tail is too large to take the tag, but the numbers so marked or the results are not given. Over 83,000 Pacific salmon had been tagged with strap tags up to the end of

1936, a few of them with the No. 44 strap, but chiefly with the No. 43. Recoveries averaged 26.9 per cent.

In 1923, William C. Schroeder commenced using strap tags on cod, haddock, and pollock, off the New England coast. He used a No. 44 strag tag measuring about 57.5 mm. in length, 6.4 mm. in width, and 0.7 mm. in thickness. He first tried tags made of silver, aluminum, copper, silver-plated copper, and monel metal. The differences in recoveries were not significant and after 1923 all his tags were made of monel. The tags were all attached to the upper lobe of the caudal fin, except in 1927, when some of the fish (number not given) were tagged on the lower jaw. Schroeder stated that although it seemed impossible for the tag to become dislodged, yet the percentage of returns from fish so tagged did not show sufficient improvement to justify the discontinuance of the tail-marking method. From 1923 to 1933, nearly 52,000 cod, over 18,000 haddock, and nearly 5,000 pollock were tagged by the United States and Canada in the western Atlantic, using the No. 44 strap on the upper lobe of the tail. However, this method can not be considered as quantitative. Schroeder mentions that their own tagging vessels recaptured 42 cod that had been at liberty at least from one year to the next and at the same time took 63 cod with scars on the tail where tags had fallen off. The use of strap tags on the tail of such fish as cod, haddock, and pollock is not recommended, as recoveries have seldom averaged over 6 per cent. The No. 37 plaice label on the caudal and the body cavity tag tried by Schroeder in 1931 and 1932 on cod in Maine, gave returns of 24.8 and 21.4 per cent, respectively.

In 1925, the International Fisheries Commission commenced using the No. 43 and No. 44 strap tags made of monel metal on halibut in British Columbia and Alaska. Their No. 43 strap tag measured 69 mm. by 8 mm. by 1.0 mm., and weighed 4 gms. Their No. 44 strap for use on smaller-sized halibut measured 58 mm. by 6.5 mm. by 0.6 mm. and weighed 1.6 gms. In 1927 they changed the No. 43 strap to 69 mm. by 9 mm. by 0.65 mm., weighing 2.6 gms. The strap tag was attached as shown in Figure 4 to the edge of the opercle on the upper side. The results have been excellent, as the percentage of recoveries has been high and the fish have retained the tags for over ten years. As the halibut grows, the tag maintains the same relative position with the edge of the opercle leaving behind it a long healed-over scar.

The No. 45 strap tag measures about 35 mm. by 3.5 mm. by 0.6 mm. and is used for smaller fish. In 1925 and 1926, Elmer Higgins tagged 6,000 mullet along the South Atlantic coast of the United States with this tag attached to the opercle, after live car experiments showed that it did not stay on the caudal fin. Recoveries were only slightly over one per cent.

Over 3,000 herring tagged in 1927 in Alaska by Rounsefell, with this tag on the upper lobe of the caudal, yielded no returns.

The No. 45 strap was used in 1932 on 614 steelhead trout in Scott

Creek, California. Out of 82 tagged steelhead recaptured, only 50 retained the tag, the others merely showing a hole in the opercle.

The No. 45 Strap (16 mm. clinched by 3.3 mm.) made out of pure nickel so that it can be recovered by the magnetic method is being used for Pacific mackerel in California attached to the opercle.

The No. 46 strap tag, also called a "fingerling" tag, was made by Carl Hubbs, of Michigan, in 1930, to use on small fresh-water species. In 1932 and 1933, Rounsefell and Dahlgren tagged 4,733 herring in southeastern Alaska with this tag, made of pure nickel and fastened to the opercle. This tag was 9.4 mm. (clinched) or about 21 mm. by 2 mm. by 0.3 mm., and weighed only 0.0675 gms. Recoveries from Sitka where both strap and body cavity types were used, gave 0.5 per cent recovery for the fingerling tag, against 4.0 for the nickel body cavity tag, so the opercle tag was discontinued. For fresh-water species, this tag has been used extensively, attached to the upper or lower jaw.

The No. 47 strap tag was developed by H. C. Godsil, to tag tuna in California. The strap is 15 mm. (clinched) or about 36 mm. by 4 mm. by 0.5 mm., made of sterling silver. The red celluloid disc is 14.5 mm. in diameter and 0.5 mm. thick, with an oblong slit in the center. The disc is slightly concave (1.5 mm.). The tag is attached as shown, to the preopercle. At first, the discs were used with the concave face to the outside, but as the tags were often torn off in handling the tuna, this position was reversed. Out of 4,000 tunas (yellowfin and skipjack) tagged in California from 1934 to 1938 none have been recaptured (Godsil, 1938).

The No. 48 strap or "Fima" tag is after Russell (1932) and was developed in central Europe, but was not found satisfactory.

Tikhy (1931) commenced marking Atlantic salmon and sea trout on the Svir River, Russia, in 1929, with a strap tag on the caudal fin. The tag measured 45 mm. by 8 mm. by 0.8 mm., so is intermediate in size between the No. 44 and No. 45 illustrated.

Strap tags have been very popular because of the speed and uniformity with which they can be applied, but experience has shown that although an excellent tag for halibut (on the opercle), they are not usually the best tags for round fish or for fish with a weak bony structure.

STURGEON

This tag is after Russell (1932), and was attached to the skin of the dorsal fin at the base of its front edge (No. 40, fig. 3).

Planning of a Tagging Experiment

In the planning of a tagging experiment there are so many factors involved that some of them are usually neglected. The first question to be answered is, "What are the aims of the experiment?"

In some of the earlier tagging experiments, the investigators desired the answer to the question of the relationship between the At-

lantic salmon (*Salmo salar*) and the sea trout (*Salmo trutta*) as it was not positively known whether the young of one would or would not grow into an adult of the other species. It was also desired to know whether a salmon would spawn twice in the same season, or whether a salmon, after spawning, would go to sea and return to spawn again, and how long it would be absent. Another prime consideration was information on the rate of growth.

Listed below are most of the pertinent questions confronting the fisheries biologist that often can be answered through the medium of successful tagging.

HOMING PROCLIVITIES

This question of homing has long been of great importance to the salmon investigations, but, owing to the difficulties encountered in discovering a tag suitable for marking young salmon, one that would remain on the fish until it returned from the sea as an adult, the answer has been obtained chiefly by mutilation of the fins of the young down-stream migrants rather than through tagging. However, fin clipping has certain inherent disadvantages. The removal of one fin is not a sufficient safeguard against the recovery of fish with one fin missing naturally. Therefore, it is necessary to remove two fins or portions of fins. Salmon workers have always hesitated to remove the pectoral fins which are of considerable importance to the fish. There remain the dorsal, adipose, anal, and left and right ventrals that can safely be clipped. This leaves but ten combinations of two fins, so that when several experiments are being carried on, the mark is too limited. Some have tried a half-dorsal or a half-anal mark in which only one-half of the fin is clipped off, but this has not found favor, as it is difficult to distinguish it from a fully clipped fin in which a few of the rays have partially regenerated. Even of the ten possible two-fin combinations, some are much preferred. The adipose or dorsal, in combination with either the left or right ventral, are considered the best, and the easiest to do. When both ventrals are clipped, two separate cuts are necessary, since the bases of the fins are attached on an angle with the sides. The anal fin is very difficult to clip on small fingerlings. The sizes of the young salmon marked vary from as large as 6 inches to as small as about 1½ inches.

In earlier years, European investigators have tried tagging the young salmon smolts. Calderwood (see Dahl and Somme, 1936) tagged 6,500 smolts in the River Tay in Scotland, in 1905, by means of a silver wire put through the front of the dorsal fin and twisted, but only 110 were recaptured. Dahl (1914) used a similar mark on 964 smolts in 1909 in the Os River, Norway. Four were later retaken at sea. Other Europeans have used a wire with a colored glass bead. George B. Kelez in 1937 marked several thousand young coho salmon on the Samish River, Washington, by a combination of fin-clipping to insure discovering the adult salmon, and a one-half-inch celluloid body cavity

tag. This method has a great advantage over the mere clipping of fins, in that the tags may be marked and any number of experiments carried on simultaneously.

The internal anchor tag (No. 49, fig. 3) remained 9 months (until the experiment had to be terminated) on young sockeye salmon held in ponds. This tag has the advantage of being externally visible, but cannot be recommended without further trial.

The most important point to stress in any experiment to determine the degree to which salmon, or other fish, return to their home stream to spawn, is that other streams be searched fully as thoroughly as the home stream for the marked fish. Failure to search these other streams in a thorough manner gives a false impression of validity to any results.

As to the numbers to be marked, it must be remembered that if the degree of wandering from the parent stream is small, then it will require a large number of recaptures in order to obtain a sufficient number elsewhere to give any reliable estimate of the percentage entering other streams.

POPULATION STUDIES

Taking for granted that the investigator has selected the proper tag and tagging technique, there remain the questions of where and when to tag, and in what numbers. For racial studies it is usually preferable to commence by tagging fish on the spawning grounds. This is well illustrated in the case of the Alaska herring, in which herring tagged in the spring on the spawning grounds at Sitka and at Craig actually overlapped in their summer feeding distribution in the region of Kuiu and Warren Island. Herring recaptured the following spring at Sitka, however, were all from the Sitka population. Only by tagging on the spawning ground, then, can one be reasonably certain of obtaining a pure population.

Tagged fish can only be returned from areas in which fishing occurs, so that failure to obtain recaptures from a certain region cannot be regarded as showing that the population does not migrate there unless one has data showing the relative amounts caught in various localities.

The only way to determine by tagging whether a population travels into an adjoining region that is insufficiently fished is to tag and release fish in such an area to discover whether or not significant numbers are retaken in the same range as the remainder of the population. Thus, one must always be on the alert to be sure that the boundaries of the range of the population as shown by tag returns are actual boundaries of the stock and not merely the limitation set on tag recovery by the intensity of the fishery.

SPEED AND RATE OF MIGRATION

Very few tagging experiments have been properly designed to show either of these factors, since the usual procedure has been to tag a large number of fish at one time and place, and then to base all conclusions on the resulting recaptures. O'Malley and Rich, in tagging sockeye salmon in Puget Sound waters in 1918, tagged throughout the summer at five different points. They were thus enabled to obtain data on the speed and the route followed by the salmon that migrated at different times during the season. Davidson and Christey (1938) tagged pink salmon each week throughout the season at Cape Chacon in southeastern Alaska during 1935 and 1936, and found that the salmon migrating past Cape Chacon during different portions of the season were bound for spawning grounds in the streams of widely separated regions.

RATES OF MORTALITY

Most early tagging experiments were of little value for determining the rates of mortality, owing to the lack of tags that would remain on the fish over long periods, and to the lack of sufficient complementary data on the age composition and amount of the annual catch. The work on the Pacific halibut by Thompson and Herrington (1930) is an outstanding example of the results that can be attained using an efficient tag coupled with detailed data on the catch.

In studying mortality rates, it is necessary to know the sizes (or ages) of the fish tagged and of those recaptured, in order to compare the rates of mortality shown by the tagging with the rates indicated by the changes in the age composition and catch per unit of fishing effort of the fishery.

GROWTH AND SURVIVAL OF TRANSPLANTS

A great deal of valuable information on the increase in growth rate of young plaice transplanted from crowded inshore areas to the offshore banks has been obtained in Europe. This necessitates measurements of the tagged fish, both at the time of release and of recapture, as well as studies of the growth of those remaining in the inshore waters. To obtain directly comparable results on such experiments, fish of comparable size should also be tagged and released on the inshore banks at the time of transplanting, so that any effect on the growth or survival, due to tagging, may be eliminated from the comparison.

SUCCESS OF HATCHERY PLANTING

Tagging has been employed with success to measure the survival of fish planted from hatcheries. This is of especial value in determining the proper season at which to liberate fish, the relative survival when planted in different habitats, and the proper size at which the fish should be planted. George B. Kelez (Rounsefell and Kelez, 1938, page

784) marked 26,000 young coho salmon in the spring of 1934 in the Samish River, Washington, that average 47.4 mm. in length. An additional 26,000 of the same stock were marked and liberated in November, 1934, at a length of 101.6 mm. From the first experiment, only 7 adults returned to the river, whereas 462 returned from the second experiment, showing conclusively the value of marking in determining the best size to rear the fish before releasing them. These fish were marked by fin clipping. In 1937, he marked several thousand by means of fin clipping and celluloid body cavity tags, which has the advantage of positive identification of each experiment.

AGE AND RATE OF GROWTH

For many species, the age and rate of growth cannot be obtained from studies of the scale structure. In such cases, the recapture and remeasurement of individual fish after a known period at liberty constitutes a very valuable means of obtaining this needed information. Even where the scale markings are of value in determining age, the recovery of tagged individuals from which scales are obtained before tagging and after recapture, forms a valuable check on the validity of the age interpretations from the scales.

SELECTION OF THE PROPER TAG

The selection of the proper tag for any experiment must depend upon several factors. The more important are:

1. *The length of time that the tag must remain on the fish.*—For some types of experiments, such as the tagging of adult Pacific salmon, in which the whole experiment can occupy only a few months, a tag such as the strap on the caudal fin has the advantage of ease, speed and uniformity of attachment. The same tag has given low returns when used to tag immature king and coho salmon at sea, as these fish may remain an additional year before entering the rivers to spawn. In most cases, the value of an experiment is increased manyfold by using the tag that remains longest on the fish. If tagging a species on which no information is available, or if in doubt as to the proper tag, it is usually much cheaper in the long run to test the various types that may fit the need.

2. *Personnel available for tagging.*—Some types of tags are much easier to apply than others. Unless the biologist can personally supervise the tagging, we do not recommend using types that require personal judgment and care. These include the Archer, Body Cavity, and Internal Anchor types. Regardless of the type of tag used, however, there is always danger of rough handling and improper technique if the work is not competently supervised. Lack of uniformity in application within an experiment or between different experiments will cast doubt on the interpretation of the results.

3. Species to be tagged.—It has been shown that tags which work well on one type of fish may be of little value on another. The indiscriminate use of the same tag on various types of fish is not likely to furnish quantitative data. For instance, the strap tag has proved to be excellent for halibut, attached to the opercle, but has proved to be very poor on cod, haddock, and pollock. Even on salmon and trout it is not recommended for any extended period of time. The body cavity tag comes the nearest to being acceptable on all species, but the disadvantage of not being externally visible often rules it out. For smaller flat-fishes the improved Petersen tag (No. 37) has given the best results to date.

For salmon and trout there are four tags now in general use—the Strap, the Archer, the Atkins (Norway), and the improved Petersen (No. 37). The strap tag is easily attached and requires less supervision, but does not remain well over long periods. The Archer is more difficult to attach and has little to recommend it. The Atkins tag has given better returns on Atlantic salmon than the Archer. The improved Petersen tag is being used by the International Pacific Salmon Commission on sockeye salmon, using a white disc with a red center and attaching it to the back for visibility while in the river. Cod tagged in Greenland with the Petersen tag although showing low percentage returns have been recaptured after a period of eight years. Recent experiments on haddock have shown the improved Petersen, the Bachelor Button (No. 16) and the large Internal Anchor to be equally efficacious over a 1-year period, but a longer time will be required to bring out the differences.

For the mackerel-like fishes, no adequate external tag has yet been applied. The collar tags used to date have caused considerable chafing of the tail. Trial of the improved Petersen on the opercle has also failed. The strap on the opercle and the magnetic internal tags have both yielded some recoveries. In all cases, however, the recaptures have been so low and have generally taken place over such a short period as to indicate need for further experimentation. The recent tagging of tuna in California with the No. 47 strap has also been unsuccessful.

For soft-bodied fishes, the celluloid body cavity tag has found considerable favor, and has been successful on the squeteague and scup. On herring and pilchards, the magnetic body cavity tag is the only successful one in use.

4. Methods of capture and handling.—The methods of capture and handing of the fish are of prime importance in the selection of a tag and in its proper application. For the larger species that are handled individually and cleaned at the time of catching, there is a large choice of tags. A fair-sized brightly-colored celluloid body cavity tag is usually found when cleaning. The fact that it may remain in the fish for a long period often outweighs the consideration of the possibility

of it being overlooked in cleaning. Kask found with halibut that were tagged with both a strap tag on the opercle and the large halibut body cavity tag that the fishermen were as likely to overlook the strap tag as the other. It is of great importance to always attach an external tag on the side of the fish that is held uppermost in cleaning.

With Atlantic coast mackerel that are shipped from the fish dealers to the markets without cleaning the body cavity tag, although it would remain in the fish, was not used as the tags would be returned from fish markets, and it would usually be impossible to discover where the fish was captured.

For small fish that are caught in millions, recourse must, of necessity, be had to mechanical recovery of the tags. The magnetic tag is, so far, the only answer to this problem.

When fish are caught in nets, there is always the possibility of tags being torn off. It is known that this sometimes occurs with the strap tag on the caudal fin, but there are no accurate data on its extent.

Methods for Recovering Tags

Every proposal for tagging fish should be accompanied with a plan for their recovery. Throughout the literature on tagging, one is confronted with failure to obtain recoveries, due to neglect of this aspect of a tagging program. There are several means by which tags may be recovered.

Archer, in 1884, when he commenced marking Norwegian salmon, also started payment of rewards for the return of the tags with information as to recapture. He fitted out a boat and personally canvassed outlying districts.

Hugh M. Smith, when tagging cod off Massachusetts in the winter of 1897-98, printed circulars and put articles in newspapers in fishing towns. In the following years he apparently neglected this precaution, and his recoveries fell off from 12.1 per cent (leaving out his tin tags) to 5.0, 1.5, and 3.7 per cent in the three succeeding years.

Fulton (1904) suggested using directions printed on silk ribbon attached to the tag, but this was not followed up.

Robert A. Nesbit greatly aided tag recovery when he commenced using celluloid for both body cavity and Petersen tags with the address to which the tag should be mailed and the fact that a reward would be paid printed on the tag. He even put full directions on the reverse side of the body cavity tags as follows:

"State when and where caught or when and from whom purchased. Measure fish by tracing its outline carefully on paper. Send about 20 scales from each side of fish."

The celluloid discs (and body cavity tags) are made of laminated celluloid, so that the printing of the red or the white disc is finally covered with a thin transparent layer of celluloid. Such attention

to detail makes a vast difference in the success of tagging experiments, as fishermen obtaining a tag without an address often will not bother to inquire about it. All too often a fisherman finding a tag and ignorant of the fact that a reward is offered for its return will keep the tag as a talisman.

The International Fisheries Commission furnishes every halibut boat, free of charge, a log book. The fly leaf describes the tagging experiments and a place in the book is furnished to record tags with the pertinent information as the fish are caught. Furthermore, agents in all the principal ports pay double rewards if they are permitted to view the fish and take otoliths and measurements.

In some instances fish buyers have been empowered to collect tags from the fisherman and pay the rewards. This method has been especially prevalent in the tagging of Pacific salmon.

With the Pacific salmon, where it is desired to discover what tributaries of the rivers the fish have ascended, it is often necessary to send parties into the field to find the tagged salmon by direct observation.

Means of recovering the tags has always deterred investigators from marking the smaller schooling fish which are taken in such large quantities that the chances of finding a tagged fish were extremely remote. Rounsefell and Dahlgren solved this problem by the use of magnetic tags and the installation of electro-magnets in fish reduction plants. This method is being employed at present for herring, pilchards, and mackerel. Dahlgren has gone a step further and made it possible to recover magnetic tags from any fish that can, in the course of handling, be passed through a coil, by the invention of an electronic tag detector which unerringly spots the presence of the metal.

In the payments of rewards it is important that the reward be sufficiently large to act as an inducement. Rewards in the United States have varied from 25 cents to $1.00, depending largely on the species of fish, the amount of information required, and the number of fish tagged. If funds for rewards are strictly limited, we advise releasing fewer fish rather than cutting the reward. It is also poor policy to vary the amount of the reward in different years, or for the same species, as such a procedure causes ill feeling on the part of the fishermen. The Fish and Wildlife Service in the North Atlantic facilitates the receipt of tags by giving out to sportsmen, dealers and fishermen a double cardboard postal card containing inside a coin envelope for the tag and scale samples, and complete directions for recording measurements and information. The address is printed on the outside of the card.

Precautions should be taken to have all advertising and publicity concerning tagging cover a much wider area than that from which the investigator expects recoveries. Otherwise an error is introduced, the amount of which cannot be estimated.

Methods for Comparing Tags

Most of the controversy existing today as to the relative merits of various tags may be traced directly to the failure to properly test tags before using them. The opinion was prevalent until very recent years, and is still held by some, that the important thing is the recapture of a tagged fish. If the tag was "inefficient" the remedy was to tag more fish.

This line of reasoning does not take into account the fact that fish may take a long period of time to emigrate from one area to another, or that data from an inefficient tag are almost worthless for estimating mortality. Even when a tag is known to be less efficient than another, there has been a strong tendency against change.

If circumstances permit, it is always wise to try various likely tags in an aquarium or live car before making field trials. In making such tests, the condition of the fish is highly important. We have found that if the fish are in a weakened condition, they may die from the effects of tagging, whereas the controls will live. The same experiment performed on healthy fish may give a totally different picture.

In an aquarium it is practically impossible to be certain that conditions of light, water supply, disease, feeding, etc., are constant for every tank. Therefore, in aquarium experiments every tank should contain controls, and if possible, the same number of fish bearing each tag to be tested should be kept in each tank. In this way, one will have as many tests of each tag as one has tanks, and if any adverse condition arises in one tank, it will affect all types of tags in a like manner. It is not always sufficient to depend wholly on the death of controls as an indication of poor conditions in any one tank, for, as we pointed out, the tagged fish may succumb to conditions not sufficiently adverse to affect the controls.

When using a live car, one may, if the fish are sufficiently small or the live car sufficiently large, achieve segregation of each type of tag, and also of the controls by portioning the live car into nine, sixteen, twenty-five, or thirty-six compartments and distributing the various experiments in a random manner, as described by R. A. Fisher (1930), so as to form a Latin square. Unless such a design can be followed, it is better to avoid partitions.

When the least efficient tags have been eliminated by aquarium or live car trials, the next step is to compare the remaining types of tags by actual liberation of sufficient numbers of fish. Many tags have been tried on so few fish that no possible judgment can be formed as to their effectiveness.

The proper procedure is to tag every second, third, or fourth fish with a different type of tag, according to the number of types to be compared. The practice that is still often used, of tagging first with one type and later with another is unsound, as then one is also comparing the difference between two lots of fish, which, even with the same tag, are likely to show a difference in the number recaptured.

In field experiments, one is testing not only the survival of the tagged fish (or retention of the tag) but also the degree to which the tags are discovered by the fishermen. The latter may vary with the position at which the tag is attached, its color, etc., and this should be kept in mind in comparing the results.

One of the chief reasons for discovering an efficient tag before starting any large scale tagging experiments lies in the difficulty of properly evaluating mortality rates, etc., if the type of tag is changed in the course of the work.

Technique of Tagging

Until recently there has been so little description of actual tagging operations that the authors have had to draw largely on personal experience for this section.

The manner in which tagging is done is determined to some extent by the physical circumstances, since tagging done at sea in rough weather is quite a different problem from tagging on a scow anchored to a trap, from a live car in a stream, or from a hatchery trough.

Strap tags come from the manufacturer on wooden or metal strips, fifty tags, in order as they are numbered, on each stick.

The discs for Petersen tags are usually in envelopes containing 100 consecutively-numbered tags mixed together. In tagging, many persons use these mixed numbers, as they come, either writing each number down as the fish is tagged, or else searching for the proper number on a prenumbered recording blank and entering the data opposite it. Such procedure cannot be too strongly condemned. It is sloppy, and is very apt to result in errors. Even if the numbers are recorded as the tagging is done, this skipping about is very confusing. It makes it especially bad if one is tagging without a recorder. Since the number is only on one disc (usually the white disc celluloid), the unnumbered discs may be kept in a shallow tray, or, as we have found preferable, the unnumbered discs can be threaded on pins in the laboratory, with the printing all facing the same way. Then the difficulty of trying to pick up discs off a board with wet hands is eliminated.

The numbered discs can be threaded onto soft wire (silver wire is excellent) in batches of 100, or whatever unit is handy, in serial order. Whenever a serial number is missing, if a piece of parchment paper or perhaps a red disc is threaded on, attention will be drawn to the missing number when recording.

Some prefer to place the discs in serial order in shallow slits cut along a board. This is handy for picking up, but is not so handy when using a large quantity of tags, which with the wire system, can all be carefully sorted in the laboratory. The wire is especially valuable at sea, since, by leaving a slight kink in the soft wire, no tags can be scattered about when the vessel pitches. The other end of the wire is simply twisted about a staple, or nail with a head, on the side of the measuring board.

For body cavity tags, R. A. Nesbit has been using coiled springs made, if not available, by simply twisting wire around a pencil, and placing 50 tags in consecutive order between successive coils. Coils are then kept in small envelopes until ready for use.

When working on deck in cold weather or when spray is flying, and especially with large active fish, the best procedure is to arrange some type of small shelter, perhaps of canvas, in which the recorder can sit and jot down measurements as the fish are handled. If scales are also taken, it is best, with this set-up, to have coin envelopes for the scales, already numbered consecutively to correspond with the tags. For tagging in calm waters, the lengths may be written on these envelopes *before* the scales are put in them, but when conditions are wet or too rough for much moving about, it is preferable to use the envelopes for scales only and record the measurements separately.

When tagging fish without a recorder it is very difficult to record the lengths with wet hands and at the same time keep the paper sufficiently dry. For this setup use convenient sized sheets of opaque white celluloid with a roughened surface.

C. H. Gilbert and W. H. Rich developed a special notebook for use on salmon, cod, or other fish in which the scales are fairly slimy. This book measures 3¾ by 6¾ inches with a heavy glazed cardboard cover. Inside there are 24 pages of high-quality water-resistant paper. Each page contains ruled spaces on one side only for placing the scales and measurements on five fish. The scales are wiped off the scaling knife onto these five spaces and then 1¼ inches of the margin of the page is folded over the scales so that they are held between the two thicknesses of paper. The slime on the scales effectually seals them in. The 1¼ inches that remains along the left side of the page is used for jotting down the measurements.

The actual handling of the fish presents many difficulties. It is seldom necessary to worry about dry surfaces, but on warm days care must be taken to keep the fish off a dry deck as they may lose too many scales.

In tagging Pacific salmon, which are extremely active, the usual procedure when using strap tags is for one man to slide the fish which another dips out of the trap onto a table, head first into a small padded box short enough so that the tail projects beyond the end. The tagger then clamps a tag on the tail and the man with the box tosses the fish back into the water beyond the trap. Davidson and Christey (1938) estimated that under favorable conditions 150 to 200 pink salmon could thus be tagged in an hour. Since these pinks were all adult two-year-old fish, no scales or measurements were required.

Concerning the tagging of striped bass with Petersen tags, Clark (1934) wrote:

> "When a bass is caught on the line, it is brought aboard the boat or on shore. The back of the fish is grasped with the left hand, using a wet gunny sack to protect the hand from spines and to prevent rubbing off of more slime than necessary.

Next, the hook is removed as carefully as possible, the gunny sack thrown over the snout of the fish, and the fish placed on its belly on a flat surface. Then with a small awl (1/16 inch in diameter), a hole is punched through the back of the fish at right angles to the length of the fish, one-quarter inch below the ridge of the back. The pin, with the white disc against its head, lettering exposed, is put through the awl hole; the red disc is put on the pin; and the pin is then curled over with a small pair of pointed-nosed pliers. The length of the fish from snout to end of tail is measured and recorded, and the fish is returned alive to the water. The whole operation of tagging takes about one minute and in no case has it seemed to weaken the fish to any extent.''

Schroeder (1930) in tagging cod off New England, stated that the use of the otter trawl was prohibited ''because a large proportion of net-caught fish are crushed or drowned by the time they are hauled out of the water.'' Most of his fish were caught with ordinary hand lines. The same would appear to hold true for haddock, as out of 562 tagged by Herrington off New England, from 1932-33, from commercial otter trawl vessels, none were recaptured. Out of 628 haddock tagged in Maine in 1938 on hook and line from a small line-trawl boat, 56 were recaptured in the first year. Belloc (1935) reported that Hickling tagged hake from otter trawls in 1931. It was necessary to trawl only about a quarter of an hour at a time, and the trawl was provided with braces to reduce the compression. The trawl, contrary to commercial practice, was hauled in very slowly to stop the too sudden decompression, which, when rapid, forces the elastic swim bladder out through the mouth. In spite of these precautions, the hake still floated belly up, and it was necessary to remedy this by puncturing the swim bladder, allowing the excess gas to escape at once. He says they have kept these punctured fish alive 48 hours, and that on returning them to the sea, they swam vigorously toward the bottom. After a number of trials, they found the best place to puncture them was behind the anus. Hansen, Jensen, and Tåning (1935) mentioned puncturing the swim bladders on a few of the Greenland cod which they caught in the deeper waters. The effect of puncturing on the number of recaptures has not so far been studied. We cannot recommend this method until it has been thoroughly tested.

As to the tagging of Pacific halibut, Thompson and Herrington (1930) stated:

''The capture of halibut for marking purposes has in all cases been accomplished by the commercial hook and line method. . . . The gear was allowed to 'soak' (remain on the bottom) from two to four hours only, instead of the more protracted period which is the accepted practice now among the commercial vessels. . . . When brought to the surface on the gear, each halibut was lifted inboard as carefully as possible by the fisherman at the roller. If the fish was hooked in such a manner that the injury was obviously mortal, it was thrown into the checkers. . . . If the injury did not appear to be certainly mortal, the ganging (short line from the hook to the ground line) was immediately cut and the fish passed over to one of the scientific assistants for tagging . . . the hook was carefully and quickly removed by means of pliers, cutters, and a specially designed wooden instrument somewhat similar to the fisherman's 'gob stick.' The degree of injury to the fish was then ascertained. If an important artery had been cut,

the gills injured, or the visceral cavity punctured or opened, the fish was discarded for tagging purposes. In all of the marking work on the banks south of Cape Spencer 36.9 per cent of the halibut caught have been tagged, and on the banks north and west of Cape Spencer 29.8 per cent.

"The halibut . . . was measured . . . on a board, or tagging 'cradle.' This was a heavy wooden trough, with a head piece across one end so designed as to fit the convex under surface of the fish. Thus the fish was held in a natural position, and when the longitudinal axis of the cradle was placed parallel to that of the ship, the concavity prevented the sliding of the fish from side to side with the roll of the vessel. . . . Measurement and the attachment of the tag were quickly done. The greatest number tagged in one day was 361, although the average was much below this. It was found that the fish could be handled as fast as brought in on the gear, so that, practically, the limiting factor for the number marked was the rate of capture."

When tagging herring in Alaska, the fish are first confined in a live car. This is usually about 10 feet wide and 20 feet long and 3 feet deep. The sides and ends are made of 2-inch planks. The bottom has alternate planks off and these openings are covered with ¼ inch mesh galvanized hardware cloth. A partition divides off two-thirds of the box. The fish are caught with a beach seine or purse seine and allowed to swim over the net into the large end of the box. A shelter is erected over the other end of the live box so that by anchoring from that end the open side of the shelter is away from the wind. In tagging the herring are first dipped into a large galvanized iron tub or half-barrel in which the water is frequently changed. One man then seizes a fish in both hands and holds it firmly while the second man makes an incision in the body wall just anterior to the ventral fin, and inserts the steel tag into the body cavity. It is possible to tag 300 to 400 per hour by this method. The tagged fish are dropped into the small end of the live car. Once or twice a day the tagged fish are released. We feel that for small school fish this method is much preferable to releasing them one at a time. Such a system soon results in a ring of predators waiting to gobble up each fish, whereas the school will swim off as a unit.

In tagging pilchards, it has not been so easy to obtain fish in sheltered spots. Consequently, the fish are often tagged from live boxes placed on the decks of vessels and provided with a circulating pump to keep the water fresh. In some cases the fish are tagged on the deck of the fishing vessels by dipping them directly out of the seine while unloading. Janssen (1937) says, "Only once have tagged fish been held to be released as a school after tagging was completed. It seems advisable to release each one immediately after tagging as the fish weaken rapidly in confinement."

Whether or not this difference between herring and pilchards in the weakening when held is due to a specific difference between the species or to the colder water and larger live box used for herring is at present a moot question. Certainly, if the pilchards weaken after a short holding period, it is a sign that the live boxes used are probably too small.

The live boxes used in herring tagging are made in sections and held by half-inch bolts and iron rods so they can be quickly dismantled. Dahlgren has substituted pontoons for cedar beams to provide buoyancy so that a live box can be quickly taken down and hoisted onto the deck of a vessel for transporting from place to place.

After cutting the incision in the side of a fish, the usual practice is to push the body cavity tag well into the body cavity. Some grasp the end of the tag in a fine-pointed pair of forceps for this operation, but for herring we found it better to push the tag into place with the end of the wooden handle of the tagging scalpel. The end of the handle is whittled down to the same width and thickness as the tag and then slightly notched so that it will not slip off the tag.

In attaching bachelor button and Petersen tags to the opercle the usual procedure is to first punch a hole with a leather punch and then attach the tag. However, in tagging haddock with the No. 37 Petersen this is unnecessary as the nickel pins are sufficiently stiff to readily pierce the tissues at the point of attachment. This smaller hole is desirable as it then takes longer to wear a large hole.

In using Petersen tags, great care must be used not to put the tag on too tightly as the result will be quick rotting of the tissues between the discs and eventually loss of the tag.

Caution should be exercised to see that tags have no rough edges. For metal body cavity tags the usual procedure is to "tumble" all tags to remove the "wire edges" left by the stamping dies. This also applies to celluloid tags. George B. Kelez found that the ½-inch long celluloid body cavity tags when used in small coho salmon (about 1¾ to 3 inches long) had to be quite smooth. The tiniest sliver of celluloid would penetrate a vital organ, and the edge of a tag, before smoothing, presented tiny tooth-like projections that were very irritating.

In tagging Pacific mackerel, Donald Fry, Jr. (1937) found that the No. 45 nickel strap tags used (⅝ inch long clinched and ⅛ inch wide or 16 mm. by 3.3 mm.) were sufficiently rough on the edges to be extremely irritating to the opercular tissues. He smoothed the tags in a drum 9 inches in diameter by two feet long, ridged inside with 16 strips of ¾ inch half round wood running the length of the drum. The whole was lined with fine emery cloth and revolved at 55 revolutions per minute for from 4 to 8 hours. Without the ridges the tags were worn too much on the ends and not enough along the edges. Nickel is heavier and tougher than most tag materials and is somewhat more apt to be left rough after stamping, so that these measures may often be omitted or modified.

Summary

It is clear that the marking of fish has expanded very rapidly. In too many instances the methods used successfully on one species have been used on another without any adequate trial.

In planning a tagging experiment the first step is to determine by

holding experiments, field trials, or both, the most efficient tag for achieving the particular aim for which the experiment is designed.

The second step is to study the fishery and from such a study to determine the best method for recovering the marked fish.

The third and perhaps the most important point is to stress great care and adequate supervision of all marking to the end that uniformity may be achieved. This will result in the elimination of one large source of variation in returns.

Finally, the catch in various areas, and a knowledge of the age and size composition of both the catch and the marked fish must be obtained for the proper interpretation of results.

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THE CATFISH FISHERY OF VIRGINIA

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Abstract

The catfish fishery of Virginia is conducted mainly on the James River and its tributaries, and on the Potomac River. The approximate average sizes of catfish taken in the commercial catches are: Channel catfish, slightly over 1 pound; white catfish, about 1 pound; and bullheads, almost one-half pound. On the basis of catch records of individual fishermen of the James River, it is concluded that the amount of fishing effort has more than doubled since 1929. Although there has been a marked increase in the amount of gear used, the volume of catch has not increased proportionately. A decrease in the average size of fish in the commercial catch seems to have occurred.

A comparison of the amount of fishing, volume of catch, and size of fish indicates that the commercial catch in the James River is probably greater than the river can continue to support without a significant decline in the size and abundance of fish. Three remedial measures are considered to be desirable and practical: First, the taking of channel catfish under 11 inches in length and of white catfish and bullheads under 10 inches long should be prohibited. Second, catfish should be culled immediately after they are caught and the undersized fish returned to the water alive. Third, a minimum size limit on dressed fish should be established.

Introduction

The catfish fishery in 1940 ranked eleventh in value and thirteenth in quantity among the commercial fish industries of Virginia (Fiedler, 1940). For 1932, the last year for which complete records are available, catfish ranked first in value among the freshwater fishes of the United States (Fiedler, Manning, and Johnson, 1934). In the upper part of the James River and its tributaries, fishermen benefit more from fishing catfish than from the better known shad, *Alosa sapidissima,* and rock or striped bass, *Roccus saxatilis.* There are two species of catfish of commercial importance in the James River: The southern channel catfish, *Ictalurus lacustris punctatus* (Raf.) and the white catfish, *Ictalurus catus* (L). The latter is commonly called the white bullhead. Also, two species of bullheads occur in the River, namely, the northern brown bullhead, *Ameiurus nebulosus nebulosus* (LeSueur) and the yellow bullhead, *A. natalis* (LeSueur). Fishermen in this area do not distinguish between the two species and both are commonly called yellow bullhead, black cat or mud cat. However, in the Potomac River white catfish, commonly called river cats, and bullheads, also called creek cats, comprise the majority of the commercial catch.

Relatively little study has been made of the biology of catfishes. Smith (1907) described briefly the breeding habits of the yellow bullhead under aquarium conditions, while Coker (1930) and Murphree (1940), working in the Mississippi watershed, outlined methods of

propagating channel catfish in artificial ponds. In addition there are several scattered references to the feeding habits of catfish.

This paper designates the relative commercial importance of Virginia catfish, and describes certain characteristics of these fish and the fishery that pertain to a development of the industry. Consideration is also given to local methods of fishing for catfish and of preparing them for market.

Size

The length-weight relationships of the channel catfish and the white catfish are shown in Table 1. With respect to the James River fishery, channel catfish with total lengths ranging from 12 to 16 inches, inclusive, constitute about 90 per cent of the total. The average length is approximately 15 inches (weight, slightly over 1 pound). White catfish are much heavier than channel catfish of the same length (Table 1). About 90 per cent of the fish in the commercial catch are between

TABLE 1.—*Length-weight measurements of channel catfish and white catfish. The average values given are based on from 12 to 40 specimens in each of the fifteen 3-centimeter size groups.*

Total length		Weight			
		Channel Catfish		White catfish	
Centimeters	Inches	Grams	Pounds	Grams	Pounds
18	7.1	......	......	50	0.11
21	8.3	60	0.13	90	0.20
24	9.4	85	0.19	150	0.33
27	10.6	135	0.30	240	0.53
30	11.8	180	0.40	340	0.75
33	13.0	250	0.55	470	1.04
36	14.2	370	0.82	700	1.54
39	15.4	500	1.12	1,000	2.20
42	16.5	650	1.43	......	......
45	17.7	825	1.82	......	......
48	18.9	1,025	2.26	......	......
51	20.1	1,300	2.87	......	......
54	21.3	1,625	3.58	......	......
57	22.4	2,000	4.41	......	......
60	23.6	2,500	5.55	......	......

11 and 14 inches long (average length around 12 inches, weight slightly under 1 pound). Channel catfish that weigh 15 pounds or more are rarely caught, and a 10-pound fish is considered large by fishermen. White catfish rarely exceed 5 pounds, and bullheads weighing over 1½ pounds are seldom taken.

Little is known of the age and rate of growth of these fish. Collections during late fall of numbers of 6-inch channel catfish apparently representing young of the year have led to the belief that a length of from 10 to 11 inches is reached by the following fall (about 18 months after the spawning period).

Reproduction

Channel catfish start to spawn in the James River in late May, and the peak of spawning activities probably is reached during late June and early July. The number of eggs per catfish is small in comparison with many anadromous fishes. However, the percentage that hatch

out appears to be relatively high. Thus Rennick (1942) studying the channel catfish found that from 20,000 eggs, 15,000 young can be reared to a length of from 4 to 6 inches. This unexpectedly high percentage of survival was obtained under ideal pond conditions where predators were kept to a minimum.

Egg counts made on James River catfish in April indicate that an 18-inch channel catfish has from 6 to 8 thousand eggs (Table 2). The counts were made by determining the amount of water displaced by a certain number of eggs. From the volume of water displaced by all the eggs of a fish, it was possible to estimate the number present in the ovary. The fish were examined about the middle of April, *i.e.*, before the spawning season; hence, the diameters listed in Table 2 were below the maximum size. Eggs of sexually mature fish examined in June were of the following sizes: Channel catfish, 3.5 to 4.0 millimeters; white catfish, 4.0 to 4.5 millimeters; and bullhead, 2.0 to 2.5 millimeters.

TABLE 2.—*Counts and measurements of eggs of catfish collected on April 16, 1943, near Jamestown on the James River*

Species	Length		Weight		Diameter of eggs millimeters	Number of eggs
	Centimeters	Inches	Grams	Pounds		
Channel catfish	41.0	16.1	672	1.48	2.5	10,600
Do.	41.5	16.3	744	1.64	2.5-3.0	5,500
Do.	45.0	17.7	843	1.86	2.0	6,500
Do.	46.5	18.3	935	2.06	2.0	4,200
Do.	48.0	18.9	1,106	2.44	2.5	6,800
Do.	48.0	18.9	1,206	2.66	2.5	7,650
Do.	49.0	19.3	1,056	2.33	2.5	7,950
Do.	49.0	19.3	1,103	2.43	2.5	8,300
Do.	50.0	19.7	1,040	2.29	2.5	8,200
Do.	52.0	20.5	1,521	3.35	3.0	10,600
White catfish	30.0	11.8	407	0.90	3.5	3,500
Do.	32.0	12.6	328	0.72	3.5	3,200
Bullhead	22.0	8.6	......	......	1.0-1.5	2,400

The male gonad is relatively inconspicuous. It consists of a central, light-colored mass from which arise small finger-like lobes that reach a length of about 8 millimeters in a 20-inch channel catfish.

Gonadal examinations have shown that in Virginia waters the female fish first reach sexual maturity at the following lengths: channel catfish from 9 to 10 inches; the white catfish, from 7 to 8 inches; and the bullheads, from 6 to 7 inches.

FOOD

Catfish are usually considered to be scavengers. Forbes (1888) found that channel catfish eat a variety of foods including vegetable matter, both dead and live fish, univalve and bivalve molluscs, and insects. He concluded that insects constitute the principal food, particularly of the young fish. According to Smith (1907), channel catfish feed on spawn of white perch, shad, herring, alewives, yellow perch, and other species. On the basis of extensive examinations of the stomach contents of bullheads, *Ameiurus nebulosus* and *A. melas*, from South Dakota, Cable (1928) concluded that while they prefer

animal food, mainly molluscs, crustaceans, and insect larvae, pupae and nymphs, they eat also plant matter. She stated that catfish do not eat eggs or young of other fish except in small amounts. In rearing young channel catfish in a pond, Murphree (1940) fed the young fry on dried, skimmed, powdered milk plus egg yolk and cod-liver oil.

Observations by the writer were restricted to channel catfish and the white catfish. Samples from 11 barrels of channel catfish caught in August, 1936, off the mud flats of the Chickahominy River indicated that they had been feeding principally on filamentous green algae. They appeared to congregate in large numbers over a local area where algae were abundant, gorging themselves on this plant, and eating little else. Stomach contents of 12 channel catfish taken on a trot-line in February, 1942, were examined. One fish that weighed 9 pounds contained three blue crabs, *Callinectes sapidus,* each about 50 millimeters in width; a second that weighed 3 pounds had an almost intact white perch, *Morone americana,* that was about 125 millimeters in length; a third had a small, partly digested fish. The stomachs of the others were without solid food. Of five fish examined later in the month, three contained small blue crabs, one having three individuals, and the other two having one crab each. No identifiable food was present in the stomachs of the two remaining fish.

Stomach contents of white catfish caught in fyke nets in the spring included herring, *Pomolobus* spp., vegetable debris, small crustacea, and a few aquatic insects. Pound-net fish taken in September had stomachs distended from eating large numbers of menhaden, *Brevoortia tryannus.*

Catfish are attracted by a variety of baits. Fishermen use menhaden, herring, mud shad or alewives (*Dorosmoa cepedianum*), and cakes made from soybean and cottonseed meals.

In the commercial fishery it has been observed that more small catfish are attracted by "bean cakes" (cottonseed and soybean meals) than by fish bait. Stale cheese and most kinds of meat are satisfactory baits.

Records show that more catfish enter pots at night and on overcast days than during bright days. This behavior may indicate that they feed principally during night-time. In general, catfishes do not appear to be very selective in their feeding habits.

Commercial Fishery

The literature on catfishes embodies little information about commercial fishing methods, size composition of the catches, and the economic importance of the fishery. The average fisherman and fishery biologist seem relatively unfamiliar with this small but locally important industry.

Methods of capture.—Approximately 80 per cent of the commercial catches in the James River area are made with cylindrical pots (3 to 4 feet long; 18 to 20 inches in diameter) made from 18- to 20-gauge woven wire of 1-inch mesh (Table 3; Fig. 1). Each pot weighs from

TABLE 3.—*Catches of one outfit on the James River, Virginia, during period 1929 to 1944*

Year	Weight (pounds)	Value (dollars)	Gear					
			Pots		Fyke nets		Haul seine	
			Number	Percentage of catch	Number	Percentage of catch	Number	Percentage of catch
1929	32,000	1,280	25	....	6	....	1	....
1930	32,000	480	25	....	6	....	1	....
1931	32,000	320	25	....	6	....	1	....
1932	35,000	350	25	....	6	....	1	....
1933	35,000	350	25	75	6	5	1	20
1934	40,000	800	35	55	6	10	1	35
1935	50,000	1,250	50	55	6	10	1	35
1936	50,000	1,250	50	55	6	10	1	35
1937	30,000	900	50	90	6	8	1	2
1938	45,000	1,125	50	90	8	8	1	2
1939	30,000	900	50	90	9	8	1	2
1940	40,000	1,200	50	90	6	8	1	2
1941	80,000	3,200	75	95	10	4	1	1
1942	64,000	3,200	100	95	12	5	1	<1
1943	80,000	4,800	100	95	12	5	1	<1
1944	75,000	5,250	100	95	12	5	1	<1

10 to 20 pounds, depending on type of construction, and costs from 5 to 8 dollars each. A pot contains 4 or 5 hoops made from 3/16- to 5/16-inch iron rods or heavy wire of No. 8 or 9 gauge. The pot has two funnels, the first at the front end and the other about a third of the way toward the rear. The remaining two-thirds of the inside is the part wherein the fish are trapped. Catfish pots are tarred to preserve them.

FIGURE 1.—Cylindrical pots used for fishing in the James River Area.

They last from one to two seasons. One or possibly two pots some distance apart are fastened to a line that is secured to a stake placed near the shore. Usually pots are weighted down to minimize shifting by currents. From 10 to 20 pounds of fish bait—mud shad, herring, or menhaden—valued at from $0.75 to $1.50 per 100 pounds, are used per trap. The bait lasts from 1 to 3 days depending on the season.

In the James River, the catch in pots is made up almost entirely of channel catfish. The other species are taken with pound nets and

fyke nets. In the Potomac area, few, if any, pots are used. Haul seines, together with pound nets and fyke nets, are employed in these waters where white catfish and bullheads predominate.

Methods of handling.—Most catfish from the James River area are sold dressed and in fresh condition. A good "skinner" receives around 2 or 3 cents per pound (dressed weight) and is able to dress from 250 to 500 pounds of catfish in 8 hours. About half of the weight of a fish is lost in dressing. The cost of labor for tending pots is around 25 dollars per week during normal times. Additional items of expense include the costs of ice for overnight storage and for shipment, motor boats, and trucks for transportation to shipping points.

Normally, a price of 4 cents per pound in the round is equivalent to about 12 cents dressed. The increase of 8 cents per pound may be expected to compensate for a 50 per cent reduction in weight through dressing and to allow 4 cents per pound to cover handling costs.

TABLE 4.—*Weight and value of annual catches of catfish and bullheads in Virginia waters during period, 1920 to 1941*[1]

Year	Weight (pounds)	Value (dollars)	Price per pound[2] (cents)
1920	826,485	48,383	5.9
1925	534,330	32,057	6.0
1929	246,525	13,420	5.4
1930	407,787	15,471	3.8
1931	609,644	25,451	4.2
1932	695,857	21,200	3.0
1933	718,408	22,351	3.1
1934	509,800	20,939	4.1
1935	481,800	15,880	3.3
1936	429,500	13,729	3.2
1937	607,100	21,468	3.5
1938	644,200	26,447	4.1
1939	584,300	27,448	4.7
1940	472,000	19,647	4.2
1941	496,400	23,170	4.7

[1]Fishery Industries of the United States 1921-41 issued by the U. S. Bureau of Fisheries during the years 1920-40 and thereafter by the U. S. Fish and Wildlife Service.
[2]Round.

Economic importance.—The annual value of the Virginia catfish fishery according to Federal statistics is about 25 thousand dollars (Table 4). Catch records of individual fishermen indicate that at least two and probably three times as many fish are caught as the official figures show. Specific records of one outfit, consisting of two men fishing in James City County on the Chickahominy River, serve to indicate the productive capacity of a known amount of fishing effort expressed in terms of gear and personnel (Table 3). During the 5-year period following 1934, this single, two-man outfit caught an average of 43 thousand pounds (value, $1,065) using 50 pots to catch approximately 70 per cent of the total. During several years, Federal figures for the total catch in James City County are below the poundage produced by this single outfit. Thus, in 1936, this outfit landed 50 thousand pounds, while official government records for the entire county show a total of 36,900 pounds. Estimates based on private records of

individual fishermen indicate that in that year approximately one-half million pounds, having a value of around 15 thousand dollars, were produced in the James River area. Considering the state as a whole, it is conservatively estimated that the average annual volume of the fishery is around one million pounds valued at from 30 to 40 thousand dollars in normal years.

In terms of a local river fishery, catfish occupy a more prominent place than has been recognized previously. This fishery may be prosecuted in conjunction with agricultural work or with other fisheries such as those for shad and rock.

Conservation

Records of individual catfish fishermen in the James River area over the period, 1930 to 1944, point definitely to a significant increase in the intensity of fishing. Our findings indicate that the amount of gear has at least doubled. The inadequacy of catch records makes it impossible to state the corresponding increase in annual catches. However, on the basis of records for 75 per cent of the outfits, it seems clear that this increase has not been in proportion to the increase in amount of gear. The fishermen not only use more gear now, but they move it more often and fish a longer season. Certain fishermen report that fewer fish are now being caught per pot, and our limited catch records bear out this opinion. Most of the operators agree that the average size of channel catfish now caught is at least a half-pound under what it was prior to about 1935.

Certain factors seem to be operating, however, toward the preservation of a stable population. In this connection attention is directed to the fact that the headwaters of the rivers are closed to commercial fishing, and thus provide protected breeding grounds. Also, these waters serve to maintain a reservoir of fish for the commercial fishing areas.

There is need for a minimum size limit that is recognized by the commercial fishermen. Results of this study support the belief that the catch of channel catfish under 11 inches long (tip of snout to tip of tail) and white catfish and bullheads under 9 inches long should be prohibited. Furthermore, the culling of catfish immediately after they are caught should be mandatory. The present practice of some fishermen is to postpone this operation until the fish are landed and dead. A minimum size limit on dressed fish should also be given consideration, as a factor in their conservation.

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PRODUCTION OF INDIANA HATCHERIES IN 1942[1]

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ABSTRACT

Live weights of fish produced in three hatcheries of central and northern Indiana were about 75 pounds per acre of largemouth and smallmouth black bass, 105 pounds of spotted or Kentucky bass, and 210 pounds of bluegills and redear sunfish. An experimental pond of year-old bluegills and redear sunfish increased in weight by 366 pounds per acre. The total annual production of warm-water fish for stocking in Indiana is estimated as about 16 tons.

Indiana's Division of Fish and Game operates 9 hatcheries for warm-water fishes. The principal species handled are largemouth black bass (*Huro salmoides*), smallmouth black bass (*Micropterus dolomieu*), spotted bass (*M. punctulatus*), bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), rock bass (*Ambloplites rupestris*), and black crappie (*Pomoxis nigro-maculatus*). The total water area in these hatcheries and a few subsidiary ponds is 95 acres.

Hatchery procedure is fairly well standardized, and remains much as described by Gottschalk (1942). The principal fertilizer used is cow manure, spread over the bottom of the pond and in piles near the edge, before the pond is flooded in the spring. About 3 tons of manure per acre of water surface is perhaps an average amount. In addition, most ponds receive treatments of soybean meal, at the rate of 50 to 75 pounds per acre per week, for about 10 weeks beginning 2 weeks before spawning time in May.

Fish for the ponds are obtained in one of two ways. The bluegills, redear sunfish, rock bass and black crappies are allowed to spawn in the nursery pond, and remain there with the fry all summer. In the autumn the pond is drained and the fish removed. The three kinds of black bass are all spawned in separate ponds; the nests are capped, the fry removed as they rise from the nest, and counted into the nursery ponds. About 30,000 fry per acre is an average rate of stocking. Unlike the pan fish, black bass are removed from their ponds several times during the season, starting in late June or July. The largest fingerlings are removed on each occasion. At some hatcheries, including those listed in Table 1, minnows seined from nearby lakes or streams are put into the bass ponds, where they are eagerly eaten. With this procedure the production of the pond may be increased substantially.

[1]Contribution number 323 from the Department of Zoology, Indiana University.

TABLE 1.—*Production, by species, of the ponds of three Indiana hatcheries in 1942.*
[Area in acres. Production in pounds per acre.]

Species	Fawn River			Wawasee			Riverside		
	No. of ponds	Area	Production	No. of ponds	Area	Production	No. of ponds	Area	Production
Largemouth black bass	3	7.80	85	13	6.39	68	1	0.91	56
Smallmouth black bass	3	6.97	58	....	....	....	7	4.08	93
Spotted bass	....	....	....	....	....	....	3	1.73	104
Bluegill	2	4.31	183	7	1.92	244	....	....	....
Redear sunfish	1	2.07	186	3	0.93	239	....	....	....
Total	[1]10	23.27	100	23	9.24	122	....	....	....

[1]Includes the rock bass pond described in the text.

The production of hatchery ponds ordinarily is expressed in terms of the number and estimated length of fish produced per acre. In 1942 it was decided to supplement this information by weighing all the fish taken from the ponds of the Wawasee hatchery at Lake Wawasee and the Fawn River hatchery at Orland, and a part of those from the Riverside hatchery at Indianapolis. Since these records of weight can be compared with production figures elsewhere throughout the country, it is felt that they may have some general interest. A summary of the data appears in Table 1. The area of the bass ponds varied from 0.3 to 3.4 acres, and there was some correlation, though perhaps not a significant one, between the size of a pond and its production; that is, the largest ponds less often produced large crops. However, only average figures for each species and each hatchery are recorded in Table 1. There was similar variation in size of the pan-fish ponds, but only three ponds (those at Fawn River) were larger than 0.4 acres. Hence it is not possible to demonstrate conclusively any effect of pond size on production.

From a comparison of the data for the different species, it is evident that production of pan fish per unit water area considerably exceeds that of the black basses. The bluegills and redear sunfish had very similar production figures at both of the hatcheries at which they were weighed: these yields were about 185 pounds per acre at Fawn River and 240 pounds at Wawasee. The difference between the two hatcheries may be associated with the much larger size of the ponds at Fawn River. The production of largemouth bass varied from 56 to 85 pounds per acre at the three hatcheries and that of smallmouth bass from 58 to 93; ponds containing spotted bass yielded 104 pounds per acre at Riverside.

Two other species were represented by one pond each. The low production of rock bass at Fawn River, 43 pounds per acre in a 2.12 acre pond, puts this species in the same production class as the black basses, but it is impossible to say whether this situation is typical. A 0.53-acre pond of channel catfish (*Ictalurus lacustris*) at Riverside produced 183 pounds per acre.

Another 0.32-acre pond at Wawasee contained hybrid sunfish obtained by crossing male bluegills and female redear sunfish. Production was rather low, as regards both numbers and weight—39,000 fish weighing 40 pounds, or 125 pounds per acre. Subsequent examination

of the hybrids has shown that practically all are male fish, so it is evident that the two species are only partially interfertile. This is a good omen, for it now seems likely that the hybrids will be almost completely sterile. The object of producing the hybrids was of course to obtain just such infertile fish, for use in small fishing ponds which tend to become overstocked, and for that reason to become unproductive.

Variability in production, from pond to pond, was evident in all species. At Wawasee, the mean of the per-acre yields of the seven bluegill ponds was 244 pounds; the range was from 154 to 294 pounds; and the standard deviation was 61.5. The production of the three redear sunfish ponds varied from 177 to 322 pounds, with a standard deviation of 73.3 from the mean of 244. Considering their smaller average yield, bass ponds were even more variable. The 13 largemouth bass ponds at Wawasee averaged 67 pounds per acre, with a standard deviation of 41.5, and a range of 31 to 160 pounds. Seven smallmouth bass ponds at Riverside averaged 90 pounds, with a standard deviation of 39.1 pounds and a range from 33 to 153 pounds. As has been observed elsewhere, good black bass production depends principally on keeping the individual fish fairly small and, above all, of uniform size, so that cannibalism is avoided. The thinning-out of the bass ponds during the summer helps considerably in approaching this ideal, but unfortunately vegetation makes it impossible to get all of the large fish out each time. The bass ponds having lowest production are usually those which contain a few dozen or hundred large cannibal fish, and a much depleted group of "regular" size (*cf.* Morris and Hale, 1942).

We will not attempt any comprehensive comparison of these figures with other published data. They do seem, however, to be of the usual order of magnitude. For example, Aldrich (1943) reported the 4-year average production of ponds near Tulsa, Oklahoma, as 147 pounds per acre of largemouth bass, and 180 pounds of bluegills. In view of the longer growing season at that latitude, it is perhaps surprising that the production of bluegills was not greater there. The high figure for bass apparently was made possible by intensive feeding with minnows and small pan fish.

Comparisons of our figures with those for ponds used for rearing adult fish are less satisfactory, because the bluegills and redear sunfish in our ponds lose a month or more at the beginning of the growing season, before they are large enough to take full advantage of the food available. Some idea of the magnitude of this loss can be obtained by comparison with a pond of 0.17 acres at Wawasee, which was stocked with 1,500 yearling fish (redear sunfish and bluegills) early in 1942. These fish weighed only 11.1 pounds when planted, but in the autumn the fish of the pond weighed out at 73.4 pounds, including 14.0 pounds of fry. The summer's growth was therefore 366 pounds per acre. This yield is much more than 294 pounds per acre, which was the best production in any pond containing fish reared from fry

of the year; it is 1.5 times the average pan-fish production at the same hatchery. The figure of 366 pounds, in fact, lies within the range of productions obtained from fertilized ponds in the course of Alabama's much longer growing season (Smith and Swingle, 1939).

At Fawn River and Wawasee, where all fish produced were weighed, the total production of all species was 100 and 122 pounds per acre, respectively. The average for all state hatcheries is probably near the first of these figures, because the others handle relatively more bass and fewer pan fish. At 100 pounds per acre, the total production of the state's 95 acres of ponds can be estimated as 9,000 to 10,000 pounds of all species. In addition, a large Federal hatchery yields possibly another 5,000 pounds. To estimate the total poundage of fish produced throughout the state there should be added also the output of more than 500 ponds, operated by Conservation Clubs and similar organizations, whose water area is about 350 acres. Their average efficiency is less than half as great as that of state ponds, but they produce relatively more pan fish and fewer black bass. If we assign them half the average production of the state hatcheries, the total fish reared for stocking in the state, each year, can be estimated as about 32,000 pounds.

It is true that this impressive figure shrinks alarmingly when divided by the area of the fishing waters of the state, but it is not our purpose here to discuss the usefulness of present stocking policies. Rather we have attempted to estimate to what extent the State and Federal governments and cooperating organizations are accomplishing democracy's professed aim of giving the public what it wants. To paraphrase Marx's definition of commodities, the nature of these wants, whether they exist in the waters of the state or merely in the imagination, does not affect the matter. But this is not to say that it will be impossible to develop a more rational demand, based on whatever real needs can be demonstrated. The experiment in producing and distributing hybrid sunfish, if it proves successful, suggests one way in which the hatcheries may eventually satisfy an economic as well as a psychological need in the community.

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THE EFFECTS OF VARIOUS FERTILIZERS ON PLANT GROWTHS AND THEIR PROBABLE INFLUENCE ON THE PRODUCTION OF SMALLMOUTH BLACK BASS IN HARD-WATER PONDS

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ABSTRACT

The bass ponds supplied with hard water at the U. S. Fishery Experimental Station, Leetown, West Virginia, are naturally unproductive of fish, due to impenetrable growths of *Chara* which invade them soon after they are filled and persist throughout the period of their operation.

The addition of cottonseed or soybean meals alone to these ponds failed to increase production over that of unfertilized ponds. When timothy hay and cottonseed meal were combined with superphosphate, increased fish production resulted. The results with hay 10 parts: superphosphate (20 per cent) 1 part were outstanding. Three ponds fertilized with this combination averaged 190 pounds of bass per acre. High production of fish is apparently correlated with plant decay.

Water blooms have not been produced consistently by any combination of inorganic fertilizers yet tried. Evidence is presented to demonstrate that their production is associated with certain nutrient elements released by plant decay.

A 12-5-5 inorganic fertilizer combination contains the proper proportions of nitrogen, phosphorous, and potash to stimulate the early spring growth of *Spirogyra* and the summer growth of *Cladophora glomerata, Oedogonium, Hydrodictyon,* and *Zygnema. Cladophora* was the characteristic summer filamentous algal form when this fertilizer was used. These algae smother out *Chara* and indirectly increase fish production.

Ponds fertilized with a 13-5-5 inorganic combination gave better fry survival and production of smallmouth black bass when filled in November 1942 and wintered wet than did ponds filled in early April 1943.

INTRODUCTION

Data have been collected during the past 4 years, 1940 through 1943, on the effects of various fertilizers on plant growths and the production of smallmouth black bass (*Micropterus dolomieu*) in ponds at the U. S. Fishery Experimental Station, Leetown, West Virginia. These observations have resulted in the conclusion that production is controlled to a considerable degree by the kinds of aquatic plants present and their condition. Plant decay apparently releases nutrients into the water, which stimulate the development of certain kinds of algae, such as *Spirogyra, Oscillatoria,* and the "water-bloom" types. Plant decay also attracts the Chironomidae, probably the most important group of aquatic insects in bass ponds. In Pond H-18 (record pond—262 pounds of bass per acre) at this station, midgefly larvae were so abundant that their cast skins formed windrows about the shore line.

The chemical changes brought about by plants in a pond are often enormous and they occur very rapidly. Observations on the methyl orange alkalinity of fertilized ponds during 1940 demonstrated the striking softening effect which *Chara* had on the mineral content of ponds with a small inflow of water. For example, in pond H-6, fertilized with cottonseed meal, the methyl orange alkalinity in parts per million (p.p.m.) of calcium carbonate was reduced progressively from 225 p.p.m. on April 29, 1940, to 71.3 p.p.m. on July 22, 1940.

In another pond treated with cottonseed meal, C-1, the methyl orange alkalinity was reduced from 160.0 p.p.m. on April 29, 1940, to 52.5 p.p.m. on July 8, 1940. In ponds receiving superphosphate the changes in alkalinity have not been so great. If such large quantities of bicarbonates and carbonates can be eliminated from solution by plants, it seems reasonable to assume that rapid changes may take place in the amounts of other essential elements. During 1940, only 30 pounds per acre of the various fertilizers were added to each pond at each application, yet the effects on the plants of those fertilizers containing small amounts of superphosphate were very pronounced.

There seems to be little doubt that the Leetown ponds, which are constructed in marl beds and supplied with very hard water, are naturally very low in fish productivity. This low productivity may be attributed to the profuse and impenetrable growths of *Chara,* naturally characteristic of the ponds. The chemical characteristics of the water conform with those of water declared to be sterile by some European workers, according to Schäperclaus (1938), who did not hold that view himself. Decline in productivity is alleged when the acid-combination-capacity (A.C.C.)[1] of the water reaches 5, the equivalent of about 140 milligrams of CaO or 220 p.p.m. of bicarbonate carbon dioxide. The fact that these limestone waters and soils are deficient in nitrogen and potassium has been borne out by observations made during 1940 and later.

Recently, Lt. Francis N. Marzulli, formerly of the Leetown staff, completed chemical analyses of the water supply, the results of which are given in Table 1.

It does not appear to have been generally recognized that the larger plants may actually reduce fish productivity in ponds in the same manner as weeds rob cultivated lands of their ability to produce desirable crops.

Smith and Swingle (1941, 1942) recommended 100 pounds of 6-8-4 inorganic fertilizer plus 10 pounds of nitrate of soda per acre to control the larger weeds in farm ponds. Fertilization for weed control, according to their recommendations, began in December or January. It resulted in the development of filamentous algae which enveloped the larger plants and caused their decay by spring. By this time, the nutrients released by the decomposition of the weeds encouraged the

[1]A.C.C. = cubic centimeters of normal hydrochloric acid per liter.

growth of phytoplankton and reduced the amount of fertilizer needed for weed control during the remainder of the year.

Our observations on the effects of fertilizers on aquatic plants apparently began about the same time under very different conditions. Just how different these conditions are is illustrated by the following facts. *Najas flexilis* and probably most of the *Potamogetons,* with the exception of *Potamogeton crispus,* die out after fruiting in the early fall in this region. Fertilization in winter in the latitude of Leetown, West Virginia, would probably, therefore, be seldom undertaken with the purpose Smith and Swingle had in view. *Chara* is described by these authors as a shallow-water, early-season form, whereas, it grows here at any depth and in any season. Locally, it is found growing on the bottoms of the limestone quarry holes at depths greater than

TABLE 1.—*Results of chemical analyses of Leetown water supply in parts per million*

Item	Reservoir A.	Reservoir B. (at outlet to ponds)	Overflow of Gray and Blue Springs (supplying Reservoir B.)	
Series of ponds supplied	C-Series	H-Series	H-Series	H-Series
Date of analysis	Dec. 6, 7, 1942	Dec. 12, 13, 1942	Early October[1]	Dec. 8, 9, 1942
Number of samples analyzed	4	4	2	4
Silica (SiO_2)	13.4	10.6	5.8	17.5
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	3.5	3.6	2.2	2.6
Calcium (Ca)	96.8	98.0	95.0	99.6
Magnesium (Mg)	12.5	13.6	11.0	12.3
Phosphorous (P), water soluble	0.004	0.003	0.005	0.005
Sulfate (SO_4)	56.6	64.4	40.9	54.7
Chloride (Cl)	7.7	8.6	6.9	9.5
Manganese (Mn)	0.0	0.0	0.0	0.0
Alkalinity (HCO_3) as $CaCO_3$	215.9	225.8	239.2	218.8
Alkalinity (CO_3) as $CaCO_3$	0.0	0.0	0.0	0.0
Alkalinity (OH) as $CaCO_3$	0.0	0.0	0.0	0.0
Total hardness as $CaCO_3$	293.0	300.6	282.5	299.2
Hydrogen-ion concentration (pH)	7.7	7.8	7.3	7.5

[1]Before the October 15, 1942, flood.

15 feet. The particular fertilizer combinations which Smith and Swingle recommended have not produced water-blooms in the hard water at this station, but filamentous algae have developed in abundance during the summer period when water-blooms ordinarily have occurred under the Alamaba conditions.

It is now evident that certain plants are more desirable in hard-water ponds than others. In general, filamentous algae are preferable to the larger aquatic plants such as *Chara, Anacharis,* various species of *Potamogeton,* etc., which naturally thrive here. On the other hand, water-bloom forms belonging to the Chlorophyceae are more desirable than the filamentous algae.

All ponds mentioned in these experiments were stocked with small-mouth black bass fry taken directly from the nest. With few exceptions, each pond was completely stocked in a single day, often from a single nest. The fry were counted individually into the ponds and

TABLE 2.—*Production of smallmouth black bass in unfertilized ponds and ponds fertilized with organic fertilizers, Leetown*

Kind of Fertilizer	Pond No.	Area (acres)	Year	Number of bass per acre	Pounds per acre	Average length (inches)	Growing season (days)	Pounds of bass per acre per day	Fry stocking rate per acre	Fertilizing rate (pounds per acre at weekly or 10-day intervals)
None (control)	H- 2	0.35	1941	5,960	74.60	3.21	113	0.66	15,000	....
do.	H-16	0.61	1941	3,702	35.34	2.93	78	0.45	15,000	....
do.	H- 2	0.35	1942	6,066	72.51	3.05	116	0.63	20,000	....
do.	H-16	0.61	1942	6,074	45.59	2.50	115	0.40	20,000	....
Average	......	......	....	5,451	57.01	2.92	106	0.54	....	....
Cottonseed meal	H- 6	0.58	1940	8,759	32.00	2.13	55	0.58	15,000	30
do.	H- 4	0.52	1941	9,179	74.75	2.96	112	0.67	15,000	44
do.	H- 6	0.58	1941	5,090	63.90	3.16	109	0.59	15,000	44
do.	H- 8	0.62	1941	9,266	61.08	2.44	112	0.55	15,000	44
do.	H- 4	0.52	1942	4,698	62.87	3.12	108	0.58	20,000	60
do.	H- 6	0.58	1942	6,095	38.16	2.49	106	0.36	20,000	60
do.	H- 8	0.62	1942	7,187	57.61	2.50	100	0.58	20,000	60
Average	......	......	....	7,182	55.77	2.69	100	0.56	....	....
Soybean meal	H- 3	0.44	1941	7,152	129.50	[1]3.60	116	1.12	15,000	40
do.	H- 7	0.58	1941	8,564	58.80	2.48	110	0.53	15,000	40
do.	H-11	0.65	1941	1,800	18.75	3.03	84	0.22	15,000	40
do.	H- 3	......	1942	4,405	[1]130.63	[2]4.02	112	1.17	20,000	60
do.	H- 7	0.58	1942	8,671	72.34	2.61	102	0.71	20,000	60
do.	H-11	0.65	1942	3,840	26.88	2.29	100	0.72	20,000	60
Average	......	......	....	5,739	72.82	3.01	104	0.75	....	....

[1]Fertilized with sheep manure 1: superphosphate 1 in 1940.

[2]Green sunfish and blackhead minnows evidently entered this pond from the drainage ditch before the plug was inserted and the pond filled. When the pond was drained 13,086 *Lepomis cyanellus* per acre (87 pounds per acre) and 7,965 *Pimephales promelas* per acre (75 pounds per acre) were found in addition to 130.63 pounds of bass per acre. Total production, 293 pounds per acre.

again individually when they were removed. The fingerlings were weighed after draining in a net for 45 seconds.

The writer is indebted to Dr. H. S. Davis, In Charge of Aquicultural Investigations, for suggestions and advice during the course of this work. He is also indebted to members of the Leetown staff who have spent many hours of overtime work assisting the writer in counting fry and removing and weighing fingerling fish from these ponds.

The Unfertilized Pond

The unfertilized ponds at this station have been characterized by growths of *Chara* which completely cover the pond bottoms. These growths appear rapidly. For example, Pond H-16 in 1942 was filled on April 16. By May 13, it was estimated that 75 per cent of the pond bottom was covered with *Chara*. By June 14, *Chara* covered the entire

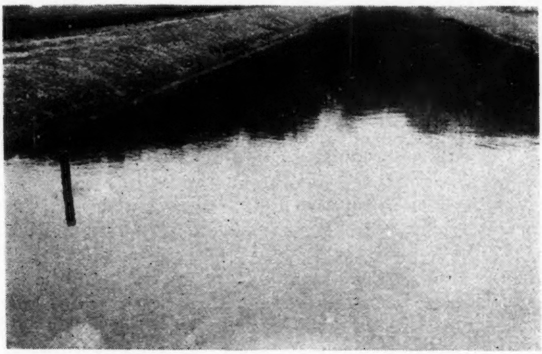

Figure 1.—Control Pond, H-16, showing surface free of scum algae, June 9, 1942.

bottom, except the banks which are sloped at a 45° angle. This growth persisted without decay throughout the entire period of the operation of the pond, increasing in height and density as the season progressed. The water in the pond remained perfectly clear and low in plankton production (less than 5.0 p.p.m.), and the surface remained free of surface algae. At no time has the production in the control or unfertilized ponds exceeded 75 pounds of bass per acre (Table 2). Where smallmouth black bass fry have been stocked directly from the nest as in all these experiments, the maximum number of fingerling fish produced per acre was 6,074, with an average length of 2.5 inches. Figure 1, a photograph of control Pond H-16 on June 9, 1942, shows the surface of a pond which has never had fertilizer of any kind added.

The typical unfertilized pond has a surface free of algae and a bottom at least 90 per cent of which is covered with *Chara*. It is becoming

apparent that some changes may be expected in unfertilized ponds as their age or fertility increases. Certain species of Potamogetons, namely, *Potamogeton foliosus, P. filiformis,* and *P. crispus* now appear occasionally in a number of unfertilized ponds as well as in ponds fertilized with soybean or cottonseed meal, probably due to increased bottom fertility. Unfertilized ponds in the C-series which have leaked badly have produced practically nothing in the way of aquatic plants except *Chara.*

Cottonseed and Soybean Meal as Pond Fertilizers

In ponds fertilized with these two meals the amounts added weekly, or at 10-day intervals, varied between 30 and 60 pounds per acre in the different years. Thirty pounds per acre were added weekly during 1940, 44 pounds[2] in 1941, and 60 pounds at 10-day intervals) in 1942 after an initial fertilization of 200 pounds per acre. The results produced on the aquatic vegetation in the ponds have been comparable to such a degree that the two fertilizers are considered jointly. Results with these fertilizers have been similar to results obtained without fertilization. Without prior knowledge that soybean or cottonseed meal had been added, it would be difficult for one to distinguish, biologically, ponds fertilized with cottonseed meal and soybean meal from unfertilized ponds. The predominant bottom vegetation in these ponds is *Chara* and the principal difference from the control ponds lies in the quantity of *Chara* produced. The maximum number of pounds of bass produced per acre in seven ponds fertilized with cottonseed meal alone has only slightly exceeded the maximum obtained without fertilizer.

The same is true of soybean meal, except for one pond, H-3 in 1940, which had previously been fertilized with sheep manure and superphosphate. The effects of this fertilizer evidently carried over into the 1941 season and possibily the 1942 season as well. The results in unfertilized ponds and in ponds fertilized with cottonseed and soybean meals are summarized in Table 2.

Potamogeton foliosus and *P. crispus* are more prevalent in ponds fertilized with cottonseed meal and soybean meal than in unfertilized ponds. However, *Chara* remains by far the dominant plant.

Among the objectives of the 1942 season was the elimination of *Chara* by heavy fertilizations with such organic fertilizers as soybean meal and cottonseed meal. Initial applications of 200 pounds per acre were made to the following ponds (Table 2): H-4, H-6, H-8, H-3, H-7, and H-11. The initial heavy application was followed by applications of 60 pounds per acre at 10-day intervals. *Chara* was not controlled, however. Neither were waterblooms, large quantities of plankton, nor fish produced, with the exception of one pond, H-3, mentioned above.

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[2]Most of the ponds during 1941 were fertilized on an "equal-nitrogen" basis. Forty-four pounds of cottonseed meal per acre per week were equal as to nitrogen content to 40 pounds of soybean meal or 37.32 pounds of 8-9-2 inorganic fertilizer.

In this pond *Potamogeton crispus* developed early over the entire pond bottom. It then died out and disintegrated, leaving the pond in a turbid condition for the balance of the season. On August 6, the oxygen content was so dangerously low in the pond that fresh water was pumped in on August 7. The turbid condition was evidently favorable, for this pond was among the highest-producing ponds of 1942.

Phosphatic Fertilizers in Combination with Organic Fertilizers

Where superphosphate has been used in combination with sheep manure, cottonseed meal, soybean meal, or timothy hay, the results have been similar. The combination of each of these organic fertilizers with superphosphate, without exception, has resulted in the production of surface scums in abundance. The green alga, *Hydrodictyon,* has been the predominating constituent of these pond scums.

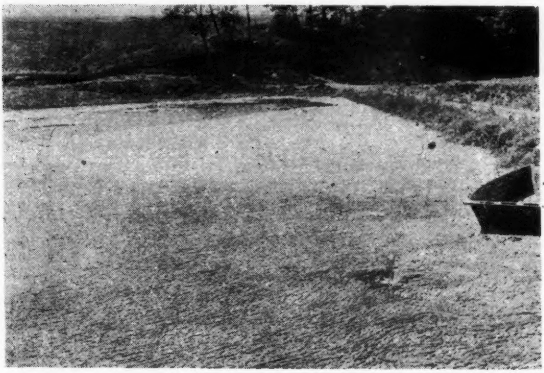

FIGURE 2.—Pond G-1, June 24, 1940. Fertilized with sheep manure 1: superphosphate 1. Note heavy scum of *Hydrodictyon* on the surface.

In 1940, where sheep manure 1 part and superphosphate (16 per cent) 1 part were used in Ponds G-1 and H-3, *Hydrodictyon* appeared as early as June 5 and remained throughout the summer. Figure 2 gives some idea of the amount of scum formed. In Table 3, the production of these ponds is shown in numbers of bass and pounds of bass per acre. In 1941, sheep manure and superphosphate were again tried with the final results given in Table 3. By May 20, *Hydrodictyon* was developing rapidly in Pond H-17, and by July 20, it was estimated that at least five-sixths of the surface was covered with this alga.

When soybean meal and superphosphate were used in the ratio of 4:1 in three ponds during 1941, *Hydrodictyon* did not develop as rapidly, but by July 20, one-half the surface of Pond H-19 was covered with this species. In Pond H-20, during the same season, *Hydro-*

TABLE 3.—*Production of smallmouth black bass in ponds fertilized with organic fertilizers plus superphosphate, Leetown*

Kind of fertilizer	Pond No.	Area (acres)	Year	Number of bass per acre	Pounds per acre	Average length (inches)	Growing season (days)	Pounds of bass per acre per day	Fry stocking rate per acre	Fertilizing rate (pounds per acre at weekly or 10-day intervals)
Sheep manure 1: superphosphate (16 per cent) 1	G- 1	0.90	1940	6,247	59.89	2.90	94	0.64	15,000	30
do.	H- 3	0.44	1940	5,559	69.89	3.07	98	0.71	15,000	30
do.	H-17	0.65	1941	2,491	34.51	[1]3.17	112	0.31	15,000	50
do.	H-18	0.61	1941	6,652	57.27	2.77	114	0.50	15,000	50
Average	......	......	....	5,237	55.39	2.98	105	0.55	....	....
Cottonseed meal 1: superphosphate (16 per cent) 1	H-19	0.61	1942	6,469	75.21	2.97	135	0.56	20,000	60
do.	H-20	0.63	1942	9,124	73.19	2.59	92	0.80	20,000	60
do.	H-21	0.68	1942	11,149	142.35	2.95	95	1.50	20,000	60
Average	......	......	....	8,914	96.92	2.84	107	0.95	....	....
Soybean meal 4: superphosphate (16 per cent) 1	H-19	0.61	1941	5,172	[2]40.47	2.50	114	[2]0.53	15,000	50
do.	H-20	0.63	1941	5,597	[2]32.04	2.47	113	[2]0.82	15,000	50
do.	H-21	0.68	1941	5,234	[2]41.26	2.64	110	[2]0.99	15,000	50
Average	......	......	....	5,334	37.92	2.54	112	0.78	....	....
Timothy Hay 10: superphosphate (20 per cent) 1	H-12	0.39	1943	6,882	159.13	3.72	111	1.43	15,000	264
do.	H-13	0.40	1943	7,288	233.91	4.20	113	2.07	15,000	264
do.	H-14	0.37	1943	5,489	176.86	3.98	113	1.57	15,000	264
Average	......	......	....	6,553	189.96	3.97	112	1.69	....	....

[1]Two large brown trout (11 and 14 inches long) were removed from this pond when it was drained. They probably entered pond through supply pipe from Reservoir B.

[2]Young black crappies, the progeny of 5 adults which had escaped as young into Reservoir B supplying the H series, were found in the following numbers in these ponds: H-19—2,000 (weight 12.5 pounds): H-20—6,080 (weight, 38 pounds); H-21—7,300 (weight, 46 pounds). Total fish production in these ponds was, therefore, corrected in H-19 to 60.96 pounds per acre; in H-20 to 92.36 pounds per acre; in H-21 to 108.91 pounds per acre. Pounds per acre per day in the last column for these ponds includes both bass and crappies.

dictyon developed to the extent that one-fifth of the surface area was covered with it by July 20. In Pond H-21, which received the same amount of soybean meal and superphosphate as H-19 and H-20, *Hydrodictyon* covered one-fifth of the surface area by July 3. In all three of these ponds failure of *Hydrodictyon* to cover more than one-half of the surface area permitted *Chara* to thrive, and in Pond H-20 it covered as much as two-thirds of the bottom area.

During 1942, cottonseed meal and superphosphate were used in equal parts in Ponds H-19, H-20, and H-21. It should be emphasized that *Hydrodictyon* has never developed in a pond fertilized with cottonseed or soybean meal alone at this station. When either meal was used in combination with superphosphate in equal parts, *Hydrodictyon* appeared, but did not become so abundant that it completely

FIGURE 3.—Pond H-21, June 9, 1942. Fertilized with cottonseed meal 1: superphosphate 1.

dominated the surface scum algae. An examination of the pond scums on these three ponds showed that *Cladophora* and *Oedogonium* were present, although *Hydrodictyon* predominated during the latter part of the season. The 1942 experiments indicate that better fish production in ponds is obtainable with this combination of cottonseed meal and superphosphate than with cottonseed meal alone (see Table 3). Figure 3 shows the typical distribution of pond scum on H-21 on June 9, 1942.

During the 1943 season, baled timothy hay was used in a productive combination with 20 per cent superphosphate at the rate of 10 parts of hay to 1 part of superphosphate. This combination was applied at the rate of 240 pounds of hay to 24 pounds of superphosphate per acre every 10 days from April 23, 1943, to July 21, 1943. The water in each of the ponds—H-12, H-13, and H-14—was turbid by May 5

with a distinct bloom recorded for Pond H-13. On June 15, the surface of Pond H12 was half-covered with *Hydrodictyon*. The bottom was draped with *Hydrodictyon* with a small amount of *Chara* in its upper end. Swarms of *Daphnia* were present, but many individuals had ephippial eggs, indicating an impending decline in their abundance. Pond H-13 at this time had 80 per cent of its surface covered with *Hydrodictyon* in a thin layer on the surface. The bottom appeared black and to be covered with decaying algae. Pond H-14 had its surface at least two-thirds covered with pond scums at this time. Again, *Hydrodictyon* was most important, making up at least half of the scum which also contained *Cladophora* and *Oedogonium*. As in Pond H-13, the bottom appeared dark and was covered with decaying algae. Several swarms of small *Daphnia* were seen in this pond.

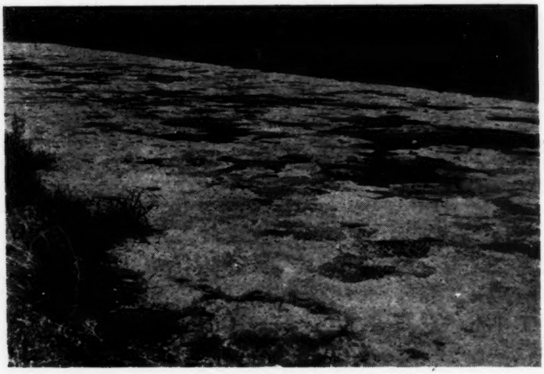

FIGURE 4.—Pond H-10, June 9, 1942. Fertilized with inorganic 9-8-2 fertilizer. Dense masses of *Cladophora glomerata* extend from the surface to the bottom, restricting the foraging areas of the bass.

By July 8, the scums on these ponds had begun to decay. Only 40 per cent of the surface of H-12 was covered with scum; in H-13, the scum had entirely disappeared from the surface and lay decomposing on the bottom. Large numbers of small Entomostraca were present. In H-14, only 10 per cent of the surface remained covered with scum which consisted of a mixture of *Oedogonium, Oscillatoria* (indicator of decay), and *Cladophora*. The color of the water was very dark.

On July 29, about 8 per cent of the surface of H-12 was covered with scum algae. Chemical precipitation was occurring in the upper end of the pond where some *Potamogeton foliosus* and *P. crispus* had established themselves. Large quantities of algae, including *Spirogyra*, were present on the bottom. The surface of H-13 was open on July 29, the bottom appeared dark from algal decay, and a light water-bloom

was present. In H-14, some *Oscillatoria* was floating in small patches on the surface. The occurrence of *Oscillatoria* in this manner is a certain sign of plant decay at the bottom of the pond. A distinct water-bloom was present, which persisted throughout the remainder of the season.

The average production of bass in ponds fertilized with hay and superphosphate was greater than any of the other experimental ponds. The decomposition of hay and algal scums undoubtedly contributed to productivity.

It seems that maximum production cannot be expected with a fertilizer and procedure which cause surface scum algae to develop to such an extent that practically all of the pond bottom is obscured throughout the summer. Pond H-21 had a large amount of surface

FIGURE 5.—Pond H-18, June 9, 1942. Fertilized with inorganic 12-5-5 fertilizer. This photograph shows the maximum development of surface scum in the pond

algae, probably about the maximum development for good production, but the scum was broken up as shown in Figure 5 and did not form a surface blanket as illustrated in Figure 2. The presence of *Cladophora* with *Hydrodictyon* is believed responsible for the distrbiution of the surface scum in "patches."

It is certain that the dense surface-to-bottom scums on H-5, H-9, and H-10 during the 1942 season, discussed in more detail below in the section on inorganic fertilizers, are excessive and might have been prevented with more experience.

Without the use of chemicals, the task of removing the fish in a pond containing large quantities of pond scums may become very great. If the scum is composed almost entirely of *Hydrodictyon*, it will float at the surface where it can be skimmed off with a seine. If *Spirogyra, Oedogoium, Cladophora,* or freshly developing *Hydrodictyon* are pres-

ent in considerable quantities at the time of the draining of the pond, many fish are probably lost during the removal. At Leetown, thick pond scums on the surface have been readily destroyed with sodium arsenite solution applied at the rate of 4 p.p.m. of As_2O_3, calculated on the basis of the total volume of water in the pond. Copper sulphate was also effective when used in concentrations of 1.5 and 2 p.p.m. Although the above concentrations of these chemicals will not kill bass directly in hard water, care must be taken that a good flow of fresh water is furnished the pond within 2 days after application of the chemical. The water may be aerated with a pump of adequate size when no supply of running water is available. Large quantities of decaying algae quickly remove dissolved oxygen from the water following these treatments and endanger fish life.

Inorganic Fertilizers and the Production of Water Blooms

When inorganic fertilizers have been used in ponds at Leetown, luxurious growths of filamentous algae have always developed. The nitrogen and potash contents of these inorganic combinations have been much higher than those of organic fertilizers or their combinations with superphosphate, and it is presumed that this difference is responsible for the prevalence of *Cladophora glomerata* during warm weather. After the first applications of inorganic fertilizers in the spring, *Spirogyra* appears first, but is gradually replaced by *Cladophora, Oedogonium,* and occasionally small quantities of *Hydrodictyon* and *Zygnema. Hydrodictyon,* considered undesirable because of its persistence, has never, with one exception, dominated a pond fertilized with the inorganic combinations used (Table 4). This exception occurred in 1940 in Pond H-5 when only 30 pounds of 8-9-2 fertilizer were being used per acre. During that season, *Hydrodictyon* covered as much as three-fourths of the pond surface by June 15. In 1941, applications of inorganic fertilizers were still light with only 37.3 pounds of 8-9-2 added per acre in Ponds H-5, H-9, and H-10. During the 1942 season, the amount per acre was increased to 115 pounds. Six consecutive applications were made with the intention of producing water-bloom, but this goal was never attained in these ponds. Instead, the masses of *Cladophora,* which appeared as early as May 12, simply became greater until they almost filled the pond from surface to bottom (Figure 4.) This great development of filamentous algae crowded the bass into relatively small areas of open water where growth was obviously retarded until fertilization ceased.

In the ponds receiving smaller applications of inorganic fertilizers, 100 pounds of 12-5-5 per application, *Cladophora* never attained the density that it did with the 9-8-2 combination (see Figure 4). The 9-8-2 combination consisted of 40 pounds of ammonium sulphate (20.57 per cent), 10 pounds of nitrate of soda (16 per cent), 60 pounds of superphosphate (16 per cent), and 5 pounds of muriate of potash (50 per cent) per acre per application, while the 12-5-5 combi-

TABLE 4.—*Production of smallmouth black bass in ponds fertilized with inorganic fertilizers, Leetown*

Kind of fertilizer	Pond No.	Area (acres)	Year	Number of bass per acre	Pounds of bass per acre	Average length (inches)	Growing season (days)	Pounds of bass per acre per day	Fry stocking rate per acre	Fertilizing rate (pounds per acre at weekly or 10-day intervals)
Inorganic, 8-9-2	H- 5	0.54	1940	8,430	50.93	2.5	78	0.65	15,000	30.00
do.	C-10	0.38	1940	8,874	115.50	3.2	93	1.24	15,000	30.00
do.	H- 5	0.54	1941	9,785	113.42	3.0	112	1.01	30,000	37.32
do.	H- 9	0.55	1941	6,669	55.00	2.6	112	0.49	15,000	37.32
do.	H-10	0.55	1941	5,971	55.68	2.8	88	0.63	15,000	37.32
Average	......	......	....	7,946	78.11	2.8	97	0.80	....	....
Inorganic, 9-8-2	H- 5	0.54	1942	3,883	68.07	3.4	106	0.64	20,000	115.00
do.	H- 9	0.55	1942	7,307	78.98	2.9	134	0.59	20,000	115.00
do.	H-10	0.55	1942	4,862	68.31	2.9	134	0.51	20,000	115.00
Average	......	......	....	5,351	71.79	3.1	125	0.58	....	....
Inorganic, 12-5-5	H-15	0.57	1942	4,012	77.52	3.4	98	0.79	20,000	100.00
do.	H-17	0.65	1942	5,728	60.35	2.9	91	0.66	20,000	100.00
do.	H-18	0.61	1942	10,433	262.44	3.9	120	2.19	20,000	100.00
Inorganic 13-5-5[1] (wet)	H- 5	0.54	1943	10,394	214.07	3.5	94	2.28	15,000	94.00
do.	H- 6	0.58	1943	8,062	169.73	3.4	97	1.75	15,000	94.00
do.	H-18	0.61	1943	9,156	169.26	3.5	125	1.35	15,000	94.00
Inorganic 13-5-5 (dry)	H- 4	0.52	1943	6,169	127.16	3.5	99	1.28	15,000	94.00
do.	H-15	0.57	1943	7,839	111.30	3.1	112	0.99	15,000	94.00
do.	H-17	0.65	1943	7,783	114.43	3.2	118	0.97	15,000	94.00
Average	......	......	....	7,731	145.14	3.4	106	1.36	....	....
Inorganic 12-5-10	H- 7	0.58	1943	9,486	113.03	3.0	99	1.14	15,000	104.00
do.	H-11	0.65	1943	6,531	105.00	3.1	107	0.98	15,000	104.00
Average	......	......	....	8,009	109.02	3.1	103	1.06	....	....
Inorganic 15-3-6	H- 8	0.62	1943	6,940	69.40	2.8	108	0.64	15,000	82.00
do.	H- 9	0.55	1943	5,755	71.59	3.1	106	0.68	15,000	82,00
do.	H-10	0.55	1943	6,971	73.49	2.8	106	0.69	15,000	82.00
Average	......	......	....	6,555	71.49	2.9	107	0.67	....	....
Grand average	......	......	....	7,320	106.58	3.1	106	0.96	....	....

[1]The 13-5-5 combination of 1943 corresponds to the 12-5-5 of 1942 in pounds of nitrogen, phosphoric acid, and potash actually added to each pond. Both series of ponds received about 12 pounds of introgen (N), 5 pounds of phosphoric acid, and 5 pounds of potash in each application. All fertilizer formulae are based on the ingredients of a short ton of the mixture.

nation consisted of 60 pounds of ammonium sulphate, 30 pounds of superphosphate (16 per cent) and 10 pounds of muriate of potash (50 per cent).

In one pond, H-18, fertilized with the 12-5-5 combination, a water bloom appeared on July 20, 1942, and persisted until the pond was drained on September 3. It followed the decay of pond scum and *Potamogeton crispus* which had become established in the pond early in the season. Figure 5 shows the maximum development of surface scum in this pond. The water-bloom algae that followed the decay of the scum and weeds consisted principally of *Coelastrum* and *Chlorella*. The production in this pond exceeded all previous records in pounds of bass per acre.

The value of the inorganic 12-5-5 combination in eliminating *Chara* from a pond was again demonstrated in Farm-pond C-8. By August 11, 1942, the bottom of this pond was completely covered with vegetation, mainly *Chara*, although a few beds of *Potamogeton foliosus* were present. A series of four applications at weekly intervals with 100 pounds of 12-5-5 fertilizer which was begun on August 17 resulted in the complete elimination of *Chara* by October 1. It is becoming increasingly evident that the use of inorganic combinations offers great possibilities for the control of the coarser vegetation and algal types in fish ponds.

Two methods of producing water-blooms in bass ponds were tried during the 1943 season at Leetown:

A.—The first method was based on variations of 12-5-5 combination of 1942 which produced water-blooms in Pond H-18 during both the 1942 and 1943 seasons. In one series of three ponds, a 12-5-10 combination was used. The amount of ammonium sulphate (60 pounds) and superphosphate (24 pounds of 20 per cent superphosphate, equivalent to 30 pounds of 16 per cent superphosphate) for each application remained the same as in the original 12-5-5 combination, but the potash was doubled from 10 pounds of muriate of potash (50 per cent K_2O) to 20 pounds per acre per application. Although the production of bass was good with the 12-5-10 combination, water blooms were not produced and apparently no benefit was derived by doubling the amount of potash.

In the second fertilizer combination (15-3-6) ammonium sulphate and potash contents remained the same, but the phosphorous content was reduced by one-half by using only 12 pounds of 20 per cent superphosphate in the combination instead of 30 pounds of 16 per cent superphosphate as used in the 12-5-5 combination of 1942. Water blooms and large quantities of filamentous algae were not produced by this new combination and the production of bass was not good. This result indicates that the inorganic-fertilizer combination for the Leetown hard water should have at least 24 pounds of 20 per cent superphosphate added for good production.

For the purpose of clarity, the formulae and composition of the

three inorganic-fertilizer combinations used during the 1943 seasons are compared in Table 5.

Water blooms appeared in the 13-5-5 (1943) series in only two ponds of six. In these two ponds (H-17 and H-18) a considerable quantity of *Potamogeton crispus* developed early in the season. This species began to die in both ponds about the end of the first week in June and water blooms appeared by June 13. Here, again, water blooms were associated with plant decay.

Up to the present time, it has not been possible to produce water blooms merely by fertilization.

B. The second method of producing water blooms was by use of chemicals followed by regular fertilization. This method apparently can be relied upon in hard water as evidenced by the following experiments:

Pond 2 (area 1.33 acres) at Moorefield, West Virginia, also supplied with hard water, (methyl-orange alkalinity, 175 p.p.m. of $CaCO_3$) was fertilized with 8-9-2 inorganic fertilizer at the rate of 105 pounds per acre per application for 5 applications weekly beginning April 18,

TABLE 5.—*Applications of inorganic fertilizers used in ponds at Leetown*

Combination formulae	12-5-5	13-5-5	12-5-10	15-3-6	9-8-2
Year	1942	1943	1943	1943	1942
Ammonium sulphate (20.57 per cent N)	60	60	60	60	40
Nitrate of soda (16.0 per cent N)	....	....	....	....	10
Superphosphate (20.0 per cent P_2O_5)	....	24	24	12	....
Superphosphate (16.0 per cent P_2O_5)	30	....	....	....	60
Muriate of potash (50.0 per cent K_2O)	10	10	20	10	5
Total pounds per acre per application	100	94	104	82	115
Total number of applications at 10-day intervals	6	7	7	7	6

1942, and ending May 14. When it became apparent that ammonium sulphate would be difficult to obtain because of the war, a change to cottonseed meal 1: superphosphate (16 per cent) 1 was made beginning May 20, and continued until July 14, 1942. By May 20, however, when the change was made, surface-scum algae were abundant. This scum was destroyed on July 24, by the addition of 17 pounds of copper sulphate. A dense water bloom followed the decay of the algae and the bass made rapid growth from this time until the pond was drained September 28, 1942, 144 days after stocking. The pond yielded 6,800 bass from 14,431 fry stocked (10,850 per acre). The bass weighed 272 pounds for an average of 205 pounds of fingerling bass per acre with an average length of nearly 5 inches. The scum algae had prevented the growth of *Chara,* and the appearance of the bloom followed the copper-sulphate treatment.

Pond G-2 (area, 0.49 acre) at Leetown, West Virginia, was treated with sodium arsenite on July 23, 1942, at a time when the entire bottom was covered with a very dense growth of *Potamogeton foliosus* and *Chara*. By the end of the month the water was dark brown. This dark brown color was probably due to water-bloom algae, but the pond

was not fertilized after the treatment and a month later began to clear up. At this time it could be seen that the *Potamogeton* had been destroyed, but the *Chara* had not been affected and had spread over areas formerly occupied by *P. foliosus.* On August 27, the pond was treated with 2.0 p.p.m. of copper sulphate. This treatment destroyed the *Chara* and when nearly a month later (September 24, 1942) the water still remained turbid, a sample was centrifuged and found to contain *Golenkinia* (a green alga) in large numbers.

Pond C-6 (area, 2.85 acres) was filled October 15, 1942. During the winter, *Chara* established itself and completely covered the bottom by spring. On June 14, 1943, the pond was treated with 30 pounds of copper sulphate (rate: 1.5 p.p.m.). By June 16, an odor of decay was very noticeable about the pond. On June 19, water-bloom algae appeared in abundance and persisted throughout the summer. The pond was fertilized June 21, June 29, July 21, and August 12, at the rate of 100 pounds of soybean meal 2: superphosphate (20 per cent) 1. The water bloom consisted of a few flagellates and several species of Chlorophyceae belonging to the following genera: *Chlorella, Scenedesmus, Ankistrodesmus, Pediastrum, Coelastrum.* Fish production in this pond was very good.

Pond C-7 (area, 2.2 acres) was filled on the same date (October 15, 1942) as C-6. *Chara* appeared through the winter and covered the bottom with a dense growth by spring. On May 31, 1943, the pond was treated with 36 pounds of copper sulphate (rate: 2.0 p.p.m.). On June 7, 1943, it was fertilized with 204 pounds of 13-5-5 inorganic fertilizer. By June 15, a good water bloom was present. The principal forms were *Chlorella, Crucigenia, Scenedesmus,* and *Ankistrodesmus.* During the summer, the principal constituents of the bloom changed somewhat, for on July 26, *Sphaerocystis* was the predominating form with *Chlorella* second in importance.

Pond C-3 (area, 0.71 acre) was filled during the first week of May 1943. By the middle of June, *Chara* appeared and the pond was treated June 17 with copper sulphate applied at the rate of 1.5 p.p.m. The pond was fertilized on June 23 with 67 pounds of 13-5-5 inorganic fertilizer. The next day a heavy water bloom appeared, consisting primarily of small unidentified green flagellates, *Chlorella, Scenesmus,* and a form belonging to the Peridinidae. This water bloom persisted throughout the summer.

Other examples could be given where the nutrient elements necessary for the production of water-bloom forms were provided by plant decay. The above evidence is considered sufficient to demonstrate that the correlation between plant decay and the production of water blooms is not fortuitous.

Meehean (1940) recorded a heavy bloom following the administration of weed killer to a pond containing considerable vegetation, and Smith and Swingle (1942) noted that fertilizer should be applied to farm ponds at a time when it would encourage the growth of filamentous

algae. They believed that most of the species of filamentous algae associated with weed control were winter or spring annuals and hence that fertilization of farm ponds should begin during the winter. This observation and others made by these writers indicate that there are other factors involved in the production of water blooms besides the proper composition of an inorganic fertilizer.

In the 1943 experiments with 13-5-5 inorganic fertilizer, three ponds were filled in November 1942 and wintered wet. In another series three ponds were wintered dry and filled early in April, 1943. All of these ponds were stocked with fry about the middle of May and fertilized with the 13-5-5 combination. The ponds which were wintered wet had better fry survival and produced more pounds of smallmouth black bass per acre than did the dry-wintered ponds (see Table 4).

Conclusions

1. Hard waters which acquire their hardness by contact with limestone formations foster the growth of *Chara*. This plant grows to such density in these waters that fish production is curtailed.
2. The addition of organic fertilizers alone to bass ponds has not increased fish production.
3. Inorganic fertilizers containing large quantities of nitrogen and potash stimulate the growth of *Spirogyra* in the spring, followed by mixed growths of *Cladophora, Oedogonium, Hydrodictyon,* and *Zygnema* in summer. *Spirogyra* is most important in the spring and *Cladophora* is most important in summer. These growths prevent the establishment of *Chara* or smother it out.
4. The inorganic fertilizers and the combination of hay and superphosphate seem to offer the greatest opportunities for weed control and fish production at present.
5. Inorganic-fertilizer combinations have not consistently produced water blooms in the pond waters at the Leetown Station.
6. Water blooms appear after plant decay. Plant decay may occur naturally, or may be induced artificially with sodium arsenite or copper sulphate.

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RESTORATION AND MANAGEMENT OF THE NEW ENGLAND ALEWIFE FISHERIES WITH SPECIAL REFERENCE TO MAINE

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ABSTRACT

To augment the fish supply in New England increased attention is being accorded to the alewife. Through neglect, obstructions to migration, overfishing, and other causes, the alewife populations have been reduced greatly. A survey of the coastal streams of Maine disclosed many streams that can be returned to production by building fishways or modifying present fishways, in conjunction with a program of restocking and proper management methods. During the 1943 season, barren spawning areas (lakes) on 13 streams were stocked with alewives and observations indicated successful production and survival of young. Recommendations are made for the removal of obstructions or the construction of fishways on 17 streams.

INTRODUCTION

The increased demand for protein food, coupled with a decrease in the available manpower and machinery, has caused a serious shortage in the fish supply. To obtain the largest poundage from the curtailed gear and manpower, the fisheries are turning to species which will yield the greatest catch for the effort expended.

In April 1942, Dr. Rounsefell pointed out that the alewife (*Pomolobus pseudoharengus*) would be sought, because it can be taken with very little labor and practically no gear. The fish are usually caught merely by dipping them out of the water as thousands crowd up the rivers during the spring spawning migration.

For many years the demand for alewives has been light, since they were used chiefly for salting, smoking, and as lobster bait. The bony structure of the alewife has restricted their use as food. However, it was found that canning softens the bones, and several thousand cases canned in 1942 found a ready market. The bulk of the increased 1943 catch was used for canning, with some pickled and an unknown, but appreciable, quantity used for home canning.

Alewives run into fewer rivers and are far less abundant now than formerly. The production of alewives by counties throughout New England in various years from 1889-1938 is shown in Table 1. It will be noted that the total catch has fallen from an average of over 10 million pounds during the first four years in which the fisheries were canvassed, to slightly over 4 million pounds during the last three years available.

These figures on alewife production are not necessarily closely associated with abundance, but to a large extent reflect the demand for the species. This is illustrated by the great drop in the catch during

TABLE 1.—*New England catch of alewives by years, counties and states*[1]

States and counties	1889	1898	1902	1905	1919	1928	1929	1930	1931	1933	1935	1937	1938
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Maine													
Cumberland	776,545	45,000	33,600	40,000	4,925	8,041	17,258	....	16,980	52,586	150,600	10,600	20,600
Hancock	759,122	631,600	399,633	531,550	254,645	435,750	361,972	501,016	948,083	192,630	653,100	548,200	556,400
Kennebec	....	....	2,750	....	....	....	....	....	....	....	....	....	....
Knox	616,750	734,925	836,850	1,099,250	553,060	380,425	1,121,000	577,716	456,298	436,240	455,200	460,800	413,900
Lincoln	1,348,550	2,382,300	659,100	768,286	364,500	714,600	759,467	750,500	675,833	581,440	1,320,000	689,400	1,052,200
Penobscot	....	8,500	....	5,000	19,000	....	....	....	....	....	....	....	....
Sagadahoc	274,100	7,500	458,900	513,000	225,200	40,600	40,500	82,000	64,000	15,000	40,400	104,000	90,000
Waldo	148,770	125,100	37,150	31,500	7,000	....	....	6,665	....	....	....	....	....
Washington	455,800	286,700	1,423,825	321,000	219,650	365,000	410,500	211,598	634,701	326,615	644,000	780,000	887,000
York	....	4,000	8,720	12,000	....	187,500	110,250	....	....	98,567	110,600	225,000	120,000
Total	4,379,637	4,225,625	3,860,528	3,321,586	1,647,980	2,131,916	2,820,947	2,129,495	2,795,895	1,703,078	3,373,900	2,818,008	3,140,100
New Hampshire													
Rockingham	140,400	325,000	475,000	122,000	....	....	58,000	....	....	....	....	....	....
Massachusetts													
Barnstable	2,756,480	1,436,531	2,948,350	1,636,300	1,632,866	360,000	106,376	361,808	487,000	314,000	9,600	33,100	195,100
Bristol	484,300	608,744	670,292	581,000	195,596	2,667	3,866	6,848	18,504	4,506	24,900	....	....
Dukes	28,100	497,561	356,008	218,280	761,150	627,240	647,050	785,940	657,475	4,400	1,500	61,100	6,000
Essex	115,632	106,600	57,200	1,808,400	29,815	523,265	287,860	197,250	237,540	396,350	550,200	231,900	269,100
Nantucket	....	....	....	37,500	56,900	....	....	....	....	....	....	....	....
Norfolk	....	....	....	29,800	....	32,000	25,000	22,500	15,000	20,000	....	....	....
Plymouth	526,104	321,995	599,000	624,900	426,050	601,500	....	397,500	744,800	175,000	348,000	430,400	480,700
Suffolk	....	....	....	....	800	101,300	315,700	18,000	51,700	8,800	24,500	329,400	6,900
Total	3,910,616	2,971,431	4,630,850	4,936,180	3,103,177	2,247,972	1,385,852	1,789,846	2,212,019	923,056	958,700	1,085,900	957,800
Rhode Island													
Bristol	1,000	30,750	35,120	24,670	....	....	....	....	22,176	10,000	5,000	22,500	19,000
Kent	....	1,000	9,800	150	....	....	....	....	....	....	....	....	....
Newport	419,000	342,000	262,120	264,270	260,550	114,570	93,439	66,050	69,432	....	15,300	58,300	47,400
Providence	13,500	17,000	8,550	....	....	....	....	....	1,620	....	....	....	....
Washington	1,088,350	757,702	289,300	309,500	9,015	46,840	25,950	120,000	33,500	166,000	35,100	137,400	114,200
Total	1,521,850	1,148,452	704,890	598,590	269,565	161,410	119,389	186,050	126,728	176,000	55,400	218,200	180,600
Connecticut													
Fairfield	....	....	....	....	....	....	....	....	720	....	....	....	....
Hartford	....	583,945	1,168,468	896,980	40,161	7,020	5,050	....	20,848	....	15,000	4,800	15,900
Middlesex	41,392	227,455	247,517	255,387	98,713	2,000	2,400	....	2,000	162	....	....	....
New Haven	8,600	12,300	20,390	7,886	500	....	....	....	....	....	....	....	....
New London	3,280	44,700	226,778	71,775	37,776	6,600	1,800	1,000	3,916	15,000	2,600	80,000	12,400
Total	53,272	868,400	1,663,153	1,232,028	177,150	15,680	9,250	1,000	27,484	15,162	17,600	84,800	28,300
Grand total	10,005,775	9,538,908	11,334,421	10,210,384	5,197,872	4,556,978	4,393,438	4,106,391	5,162,126	2,817,296	4,405,600	4,206,900	4,306,800

[1]Figures published by the U. S. Bureau of Fisheries, including only those years in which figures were published by counties.

1933, when the prices of the more popular species of fish were at extremely low levels. Because of the scattered nature and seasonal character of the alewife fisheries it is difficult for statistical agents to obtain complete records of the annual catch by the method of canvassing the fishermen once a year, as was employed in the past. For this reason, these catches should be considered as minimum. However, these figures suggest great changes in the productive capacity of various localities due to the disappearance or diminution of the runs to certain rivers.

The catch in the Connecticut River, which according to H. M. Smith (1899) was the second river in New England in the production of alewives, amounted, in 1896, to 795,000 pounds or 79 per cent of the total catch for Connecticut. This great run has almost disappeared and the total catch for the state is now negligible. (Table 2.)

TABLE 2.—*New England alewife catch by states*[1]

Year	Maine	N. H.	Mass.	R.I.	Conn.	Total	
						Pounds	Value
1880	1,804,202	425,000	3,751,059	2,978,000	770,000	9,728,261	$103,285
1887	2,754,819	100,450	4,130,277	1,560,300	17,600	8,563,446	113,952
1888	3,079,994	146,750	6,291,936	1,739,300	25,200	11,283,180	138,130
1889	4,379,637	140,400	3,910,616	1,521,850	53,272	10,005,775	103,751
1896	3,388,326	293,671	5,356,489	2,076,960	1,001,188	12,116,634	113,420
1898	4,225,625	325,000	2,971,431	1,148,452	868,400	9,538,908	76,959
1902	3,860,528	475,000	4,630,850	704,890	1,663,153	11,334,421	89,289
1905	3,321,586	122,000	4,936,180	598,590	1,232,028	10,210,384	92,957
1908	2,525,000	121,000	4,574,000	288,000	1,026,000	8,534,000	81,200
1919	1,647,980	....	3,103,177	269,565	177,150	5,197,872	121,700
1924	1,168,077	....	2,592,299	405,737	116,306	4,282,419	53,229
1928	2,131,916	....	2,247,972	161,410	15,680	4,556,978	51,954
1929	2,820,947	58,000	1,385,852	119,389	9,250	4,393,438	40,126
1930	2,129,495	....	1,789,846	186,050	1,000	4,106,391	36,722
1931	2,795,895	....	2,212,019	126,728	27,484	5,162,126	41,701
1932	2,296,287	19,800	1,164,283	72,470	19,339	3,572,179	18,739
1933	1,703,078	....	923,056	176,000	15,162	2,817,296	16,837
1935	3,373,900	....	958,700	55,400	17,600	4,405,600	25,467
1937	2,818,000	....	1,085,900	218,200	84,800	4,206,900	21,986
1938	3,140,100	....	957,800	180,600	28,300	4,306,800	19,985
1939	2,954,300	....	946,000	22,600	13,800	3,936,700	27,494
1940	2,260,300	....	879,000	20,200	33,900	3,193,400	19,141

[1]Figures published by the U. S. Bureau of Fisheries and by the Fish and Wildlife Service.

In 1880 the Rhode Island catch was 2,978,000 pounds, but fell steadily to a low of 20,000 pounds in 1940. The Rhode Island catch came chiefly from a large number of small streams and brackish shore ponds. The run in the Warren (Palmer) River, which produced 161,000 pounds in 1896 has fallen to very small proportions due largely, according to Belding (1921), to lack of uniform fishing regulations between Rhode Island and Massachusetts. Until the problems of pollution, impassable dams, and stream flow have been solved, it is doubtful whether sizable alewife runs can be restored in Rhode Island.

The alewife fisheries in Massachusetts have seriously declined from their former abundance. Averaging between four and five million pounds in the period between 1880 and 1896 the production has declined to an average of one million pounds in the last ten years.

David L. Belding (1921) in a report of the Division of Fisheries and Game of Massachusetts sums up investigations made between 1912 and 1920, showing that the decline in the fisheries was caused by impassable dams, pollution, overfishing, and the elimination of spawning grounds. Largely as a result of the interest aroused by the deplorable conditions brought out in Belding's report fishways have been constructed over several of the impassable dams and repairs and alterations made in many existing fishways. Overfishing has been caused to a great extent by the practice of the towns of leasing the fishing rights to the highest bidder, usually for only one season. This system of short-time leases puts a premium on exploitation, as the successful bidder has no financial interest in the future of the fishery.

Although pollution has been abated to some extent, the highly industrialized character of the coast of Massachusetts renders it doubtful whether many of the streams in congested areas can be cleared of pollution at a cost commensurate with the possible value of the alewife runs.

The extension of the alewife fisheries in Massachusetts, except for the building up of existing runs, is seriously handicapped by the elimination of many of their former spawning grounds. More and more ponds and lakes are being reserved for water supplies. Other streams have been diverted for the flooding of cranberry bogs.

The greatest opportunity for the restoration of a really large alewife run in Massachusetts is afforded by the Merrimac River. Even as late as 1896, with the river dammed at many points, it produced 472,500 pounds of alewives, the fourth largest producer in New England. The present run is of negligible proportions.

At one time alewives abounded in several rivers in New Hampshire, especially the Piscataqua, Exeter, and Newmarket. However, according to Atkins (1887) in 1880 the main upper tributaries of the Piscataqua had been dammed for over 200 years and the main river itself had more recently been obstructed. In 1896 the catches of these three rivers (Smith 1899) were Piscataqua, 24,000 pounds; Newmarket, 26,000; and Exeter, 244,000. Since then the alewife fisheries of New Hampshire have further declined until there are now no runs of commercial importance.

The alewife catch in Maine has held up better than in any of the other New England states. In the six years in which statistics were collected between 1880 and 1898, Maine accounted for 32 per cent of the average New England catch of 10,200,000 pounds. In the last six years on which statistics are available, from 1933 to 1940, Maine produced 78 per cent of the average production of 3,478,000 pounds. The decrease in Maine production between the earlier and later periods was only 17 per cent, from 3,272,000 to 2,708,000 pounds. In the remainder of New England the catch fell from 6,934,000 to 770,000 pounds or a decrease of 89 per cent.

The decline in abundance and in the number of runs in Maine has

actually been far greater than would appear from the statistics, as is brought out in detail below. Because of the great possibilities for development and restoration, Maine was chosen for the first season's work on alewives.

Life History of the Alewife

Adult alewives ascend the streams in the spring for spawning purposes. Since the eggs are not deposited until the water temperatures have risen to suitable heights (usually 55° to 70° F., Belding 1921), the migration in general occurs earlier in the southern part of New England. The runs south of Cape Cod make their first appearance between the last of March and the middle of April. In central Maine, they appear between the last of April and the first week of May. In most of the streams in eastern Maine alewives are not expected until after the first of May.

Alewives spawn chiefly in lakes and quiet stretches of stream. However, we have observed them spawning in a moderate current, when more suitable places were not available.

The eggs are adhesive and cling tightly to stones, sand, and other material on the bottom. The incubation period is very short, ranging from 48 to 96 hours at 72° F. (Belding 1921) to six days at 60° F. (Bigelow and Welsh 1925).

The young develop rapidly, descending to salt water at a length ranging from one and one-half to four inches. In the Pemaquid River young alewives were entering salt water on July 14, 1943 at a length of less than one and one-half inches. This however is exceptionally early for alewives to be descending streams in Maine. Careful inspection, at this time, revealed no young descending the two largest alewife-producing rivers in this vicinity, the St. George and Damariscotta. In 1941 the bulk of the young alewives descended the Pemaquid during August and a sample taken on August 12 averaged about one and three-quarters inches in length. It is generally reported that the bulk of the young alewives customarily migrate to salt water from late August through September.

The adults return to salt water so soon after spawning that they often pass through the last of the incoming run. Although it is generally taken for granted that the great majority of the adults survive to return to salt water, yet we have observed numbers of dead adults in some streams. What proportion of the adults that reach the sea survive to spawn a second time is a moot question. Belding (1921) is of the opinion that they probably spawn but once. Our examination of scales from the 1943 runs in the Orland and Damariscotta Rivers in Maine and the Nemasket River in Massachusetts indicated that in each river almost the entire catch was composed of one age group. This strongly suggests that very few adults spawn more than once. This question can be settled later from analyzing the returns from the stocking experiments.

TABLE 3.—*Length and weight of alewives from three New England rivers in 1943*

Item	Males			Females		
	Nemasket River	Damariscotta River	Orland River	Nemasket River	Damariscotta River	Orland River
Number of specimens	38	191	349	45	227	301
Average length in millimeters	257.8	268.9	269.7	266.9	275.0	278.2
Average weight in grams	241.3	244.7	241.0	284.1	273.4	279.3
Weight in grams from regression curve of weight on length:—						
at 225 millimeters	189	178	146	191	158	162
at 250 millimeters	228	217	197	241	211	213
at 275 millimeters	269	257	254	299	269	268
at 300 millimeters	314	301	322	364	339	334
at 325 millimeters	361	349	406	437	422	411

The length of time that these fish spend at sea seems to vary from southern to northern New England. Belding reports from stocking experiments in Massachusetts that mature fish return to a stream three years after adults have been planted there for spawning. The U. S. Fish Commission (1874) states that when several hundred spawning alewives were placed in Keene's Pond, which had an outlet into the Calais River, Maine, adults returned to spawn four years after. We obtained scale samples from three rivers, one having its mouth south of Cape Cod (Nemasket) and two in Maine (Damariscotta and Orland). Examination of these scales showed three checks on 78 out of 83 samples from the Nemasket River. Samples from the Damariscotta River showed four checks on 83 out of 88 examined. Orland River alewife scales showed four checks on 25 out of 25 examined. This would indicate that we may expect returns from stocking experiments in Maine rivers about four years from the time planted.

The difference in age between the alewives from the Nemasket River and those from the Damariscotta and Orland Rivers is reflected in their size. In all three rivers the females averaged between six and nine millimeters longer than the males. Comparing fish of the same sex, the Nemasket River males averaged 258 mm., while those from Damariscotta and Orland Rivers average 269 and 270 mm., respectively. For females the averages are 267 mm. for Nemasket against 275 and 278 mm. for the northern rivers. The lengths and weights of these samples are summarized in Table 3. It will be noted that the weight for any given length, as taken from the regression curve of weight on length, is greater for Nemasket alewives than those of the northern rivers, regardless of sex.

Although our evidence indicates that the alewives in the Damariscotta and Orland Rivers are predominantly four years of age, we hesitate to suggest that this holds true in all Maine rivers. We have been informed that the alewives from certain streams consistently average noticeably smaller than those from other streams in the same locality. It is quite possible that an earlier seaward migration of the young or a different fresh water environment might cause the fish from some streams to mature sooner.

Suitability of Maine Rivers for Alewives

The first step in a restoration and management program for the Maine alewife fisheries was to obtain detailed information on the present and former runs and on the present suitability of individual streams for the development and maintenance of commercial runs.

As a preliminary step in this survey a list was prepared, from topographical maps, of all the streams of any size emptying into salt water between Kittery and Calais. The lake and pond areas of these 115 streams, with the exception of the St. Croix. Penobscot, Kennebec and Androscoggin, were calculated by means of planimeter measurements, except those for which the areas are published in the State of Maine fish survey reports. (Cooper 1939a, 1939b, 1941, 1942.)

TABLE 4.—*Alewife runs and lake areas on 115 Maine streams*

Name of stream	Alewife run		Lake area in acres		Sources of information[1]	Remarks
	At present	Formerly	Area accessible	Total area		
YORK COUNTY						
Spruce Cr.	None	None	0	0	W	....
Brave Boat Cr.	None	None	0	0	W	....
York R.	Poor	....	46	46	W, F	Stream small and very brushy.
Cider Hill Cr.	?	?	?	87		Probably the "York" river reported with a poor run.
Cape Naddick R.	None	None	?	157	W	....
Josias R.	None	None	0	0	W	....
Ogunquit R.	None	None	3	3	W	....
Webhannet R.	None	None	?	2	W	....
Merriland R.	None	?	0	12	W	....
Branch Br.	None	?	?	3	W	....
Mousam R.	Poor	Yes	0	1,842+	W, O	Dams near mouth.
Kennebunk R.	Poor	....	0	244	W	Dams near mouth.
Batson R.	None	?	0	3	W	....
Little R. or Davis Br.	None	?	3	3	W	....
Saco R.	Poor	Yes	?	4,204+	W, F, O	343 acres accessible if fishways at Saco are passable
Goosefare Br.	None	None	0	0	W	....
CUMBERLAND COUNTY						
Little R.	Fair	....	20	20	W	....
Scarboro R.	None	....	0	0	O	....
Nonesuch R.	None	....	0	0	O	....
Red Br.	None	....	?	10	O	....
Stroudwater R.	None	....	0	0	O	....
Presumpscot R.	None	Good	0	28,787+	O	Formerly entered Sebago Lake
Royal R.	None	?	0	250	F, O	....
Cousins R.	None	....	0	0	O	....
Bunganuc Cr.	None	....	0	0	W	....
SAGADAHOC COUNTY						
Androscoggin R.	None	Yes	0	0	O	....
Whiskeag St.	Poor	....	15	15	W	....
Winnigance St.	Fair	....	?	39+	W	....
Nequasset Br.	Good	Good	430	430	W, F, O	....
McFarlin's St.	Poor	....	?	6	W	....
Cathance R.	?	Yes	?	16	O	....
Abagadassett R.	?	....	0	0	O	....
KENNEBEC COUNTY						
Kennebec R.	None	Excellent	0	....	O	Formerly ascended to Norridgewock Falls.
Cobboseecontee St.	None	Excellent	0	11,546+	O	....
Nehumkeag Br.	?	Yes	?	183	O	....
LINCOLN COUNTY						
Eastern R.	?	Yes	?	73	O	....
Sheepscot R.	Poor	Good	0	2,839+	W, F, O	Sheepscot Pond stocked in 1943.
Dyer R.	Poor	Yes	0	576	W, F,	....
Deer Meadow Br.	?	....	?	80		
Lily Pond St.	None	Yes	63	63	F, O	Lily Pond Stream stocked in 1943.
Back River St.	Poor	Yes	0	64	F, O	Used as a water supply.
West Harbor Cr.	None	Good	159	159	F	West Harbor Pond stocked in 1943.
Damariscotta R.	Very good	Excellent	4,463	4,463	W, F, O	....
Pemaquid R.	Fair	Good	50	2,803	W, F, O	Pemaquid Pond stocked in 1943.
Muscongus Br.	Poor	Yes	253	253	W, F,	Stream partially obstructed.
Medomak R.	Poor	Good	0	809	W, F, O	Medomak Pond stocked in 1943.
Goose R.	None	....	?	48	O	....

TABLE 4.—*Alewife runs and lake areas on 115 Maine streams*—(*continued*)

Name of stream	Alewife run: At present	Alewife run: Formerly	Lake area in acres: Area accessible	Lake area in acres: Total area	Sources of information[1]	Remarks
KNOX COUNTY						
St. George R.	Good	Excellent	1,569	5,745+	W, F,	Needs several fishways.
Oyster R.	None	?	?	110	O	....
Mill R.	?	?	0	343	O	Used as a water supply.
Tenants Harbor Marsh	None	Yes	0	10?	W	....
Weskeag R.	None	Yes	0	0	W	....
Goose R.	None	None	0	80	F, O	Steep natural falls.
Megunticook R.	None	?	0	1,332+	O	....
Vinalhaven St.	Poor	....	0	164	O	....
WALDO COUNTY						
Ducktrap R.	Good	Yes	816	1,040	W, F, O	....
Little R.	None	....	0	0	F, O	Used as a water supply.
Passagassawaukeag R.	Poor	Yes	0	567	W, F	....
Wescot St.	None	....	0	50	F	....
Goose R.	None	....	0	1,370+	F, O	....
Searsport St.	Poor	....	0	56	F	....
Marsh R. or Colson St.	?	....	155	155	O	....
Marsh St.	None	....	0	156+	F, O	....
PENOBSCOT COUNTY						
Souadabscook St.	Poor	....	0	456	F, O	
Penobscot R.	Poor	Yes	?	....	F, O	....
Sedgeunkedunk St.	Poor	....	?	....	F, O	....
	Poor	....	0	1,195	O	....
Mill Cr.	Poor	....	125	125	F	....
HANCOCK COUNTY						
Mill St.[2]	None	....	0	48	W, F,	Used as a water supply.
Orland R.	Very good	Excellent	1,403	3,915	W, F, O	....
Pierce Pond St.	None	....	0	111	F	Steep gradient, could possibly be made accessible.
Winslow (Cove) St.	Poor	....	0	125	F	Wight Pond stocked in 1943.
Parker Pond St.	None	....	0	52	W, F,	Small summer flow.
Walker Pond St.	Fair	Good	697	697	W, F, O	Fishway needs attention.
Carleton St. or Allen Mill St.	Poor	Good	0	411	F, O	Second Pond stocked in 1943.
Mill St.[3]	None	....	0	0	F	....
Peters Br.	None	....	0	30	F	Stream small and brushy.
McCards St.	None	....	0	16	F	Stream small and brushy.
Western (Mill) Br.	Poor	None	0	0	F	Alewives were introduced here.
Patten St.	Poor	Good	1,102	1,102	W, F, O	Fishways need attention.
Union R.	Poor	Good	0	31,751+	F, O	Very high dam near mouth.
Kilkenny St.	None	....	0	0	F	....
Egypt St.	None	....	0	0	F	....
Taunton (Mill) Br.	Good	Yes	345	345	W, F, O	....
Card Mill St. or Hog Bay St.	Good	Yes	715	715	W, F, O	....
Little Pond St.	None	....	0	28	F, O	High natural fall.
Basin Pond St.	None	....	7	7	F	Very small stream
Flanders St.	None	....	555	555	F	Flanders Pond stocked in 1943.
Morancy St.	None	....	60	60	F, O	Morancy Pond stocked in 1943.

TABLE 4.—*Alewife runs and lake areas on 115 Maine streams*—(*continued*)

Name of stream	Alewife run: At present	Alewife run: Formerly	Lake area in acres: Area accessible	Lake area in acres: Total area	Sources of information[1]	Remarks
Jones St.	Good	....	360	360	W, F, O	....
Prospect Harbor St.	Poor	Good	196	196	W, F,	....
West Bay St.	None	....	0	300	F	West Bay Pond stocked in 1943.
Chicken Mill St.	None	....	0	50	F	
Seal Cove Br.	Poor	....	0	315	W, F,	Seal Cove Pond stocked in 1943.
Denning Br.	Poor	....	0	244	F	Echo Lake stocked in 1943.
Great Pond St.	Fair	....	1,053	1,053	F	....
Richardson Br.	None	....	?	28	F	Stream small.
Hadlock Pond St.	None	....	?	69	F	Stream small.
Jordan St.	Poor	....	211	211	F	Obstructed in summer by gravel seawall.
Northeast Cr.	None	....	0	0	F	....
WASHINGTON COUNTY						
Whitten-Parrin St.	None	None	0	0	W, F,	
Tunk St.	?	Yes	0	3,237	F, O	Tunk Lake stocked in 1943.
Narraguagus R.	?	Good	?	1,430+	F, O	Dams destroyed by ice in 1942.
Harrington R.	None	None	0	0	F	....
Pleasant R.	Poor	Good	0	860	W, F, O	Fishway needs observation.
Indian R.	None	....	0	0	O	....
Chandler R.	Poor	Poor	0	0	W, F,	....
Machias R.	Fair	Good	9,576	9,576	W, F,	Difficult natural fall at mouth.
East Machias R.	Very good	Good	9,824	15,408	W, F,	....
Holmes St.	?	....	?	60		....
Orange (Whiting) R.	Poor	Good	0	1,868+	W	....
Little Falls St.	?	....	?	20		
Dennys R.	Good	Good	9,007	10,740+	W	Fishway at Meddybemps Lake needs to be kept open.
Pembroke R. or Pennamaquan R.	None	Excellent	0	1,904	W, O	....
Boyden St.	?	....	?	1,728	....	....
St. Croix R.	Poor	Yes	0	....	W, O	....

[1]W—Warden's report (Sea and Shore Fisheries); F—Our inspection (Fish and Wildlife Service); O—Other information.
[2]In Bucksport.
[3]In Bluehill.

Commissioner Arthur Greenleaf of the Sea and Shore Fisheries Department sent questionnaires to the warden of each district asking for certain information on local streams. More or less complete information was sent in on 52 streams. The authors made a personal inspection of 64 streams, with special attention paid to fishways, dams, natural obstructions, stream flow, and extent of spawning areas. Photographs were taken of most of these features. Information on some streams was received from various other sources. Altogether some information was obtained on 110 streams.

The complete list of streams arranged from south to north following the coast is given in Table 4. An analysis of these data indicates that there is a distinct relationship between the lake area accessible to

alewives and the size of the run in each stream. Thus Table 5 shows that no streams with less than 20-39 acres of lake have a commercial fishery and none of the rivers supporting regular fisheries have less than 320 acres (one-half square mile) of lake area. Therefore in discussing the possibilities of restoration work by counties the streams with less than 40 acres of lake surface have been ignored.

The number of streams in each county classified according to lake area appears in Table 6. It will be noted that of the streams (72 out of 111) with over 40 acres of lake, only 12 lie in the four southern counties, 25 lie in the three central counties, and 35 in the three eastern counties.

TABLE 5.—*Relationship between the lake area accessible to alewives and the importance of the run in Maine streams.*[1]

Lake area accessible	Importance of the alewife run[2] ?	None	Poor	Fair	Good	Very good	Total number of streams
Acres							
?	9	8	2	1	....	....	20
0-9	3	44	23	....	....	....	70
10-19	....	....	1	....	....	....	1
20-39	....	....	....	1	....	....	1
40-79	....	....	1	1	....	....	2
80-159	1	....	....	....	....	....	1
160-319	....	....	....	....	....	....	0
320-639	....	....	....	....	3	....	3
640-1,279	....	....	....	2	3	....	5
1,280-2,559	....	....	....	....	....	1	1
2,560-5,119	....	....	....	....	....	1	1
5,120 and over	....	....	....	....	1	1	2
Total	13	52	27	5	7	3	107

[1]Does not include Lily Pond Stream or Flanders Stream in which former runs were totally destroyed; West Harbor Creek which became accessible in 1943. Mill Creek (So. Orington), Muscongus Brook, Patten's Stream, Jordan's Stream, and the Machias River, all of which are partially obstructed by natural barriers or poor fishways.

[2]"?" means no definite information. In no case marked "?" is there a commercial run. A "poor" run is too small to be used commercially. A "fair" run is used commercially but does not support a regular fishery. "Good" and "Very good" runs support regular alewife fisheries, the difference between the two being based on the size of the run.

York County.—Only 6 streams in York County contain over 40 acres of lake surface in their drainage. The Warden's reports indicate poor alewife runs in the York, Mousam, Kennebunk, and Saco Rivers. The southernmost of these, the York River, has no record of ever having had a commercial run. The Mousam and Kennebunk Rivers have several dams without fishways, and therefore no commercial run can be expected. Most of the large lake area of the Saco River is also blocked by dams. The dams at the town of Saco are reported to be provided with fishways, but no information was obtained on their effectiveness. If these dams are passable 343 acres of lake is accessible. As a whole the outlook for alewife restoration in York County is discouraging at present.

Cumberland. County.—The only streams with over 40 acres of lake area are the Presumpscot and Royal Rivers. At one time alewives

TABLE 6.—*Lake area of Maine streams by county*[1]

County	Lake area of streams in acres											Totals			
	0-9	10-19	20-39	40-79	80-159	160-319	320-639	640-1,279	1,280-2,559	2,560-5,119	5,120 and over	Under 40 acres	40-159 acres	Over 160 acres	Grand total
York	9	1	....	1	2	1	....	....	1	1	....	10	3	3	16
Cumberland	5	1	1	....	....	1	....	....	....	....	1	7	....	2	9
Sagadahoc	2	2	....	1	....	....	1	....	....	....	....	4	1	1	6
Kennebec	....	....	....	....	....	1	....	....	....	....	1	....	....	2	2
Lincoln	....	....	....	4	2	1	1	1	....	3	....	....	6	6	12
Knox	1	1	....	....	2	1	1	....	1	....	1	2	2	4	8
Waldo	1	....	....	2	2	....	1	1	1	....	....	1	4	3	8
Penobscot	....	....	....	....	1	....	1	1	....	....	....	....	1	2	3
Hancock	6	1	3	5	2	5	4	4	....	1	1	10	7	15	32
Washington	4	....	1	1	....	....	....	1	4	1	3	5	1	9	15
Totals	28	6	5	14	11	10	9	8	7	6	7	39	25	47	111

[1]Exclusive of the Androscoggin, Kennebec, Penobscot and St. Croix.

ascended the Presumpscot into Sebago Lake (Atkins 1887) but at present a series of impassable dams has eliminated it for alewives. The Royal River is blocked close to the mouth by two dams. The first is about 7 feet in height built of concrete. The second dam is of masonry about 9 feet in height, but a ledge in the center of the stream would facilitate the construction of a fishway.

Sagadahoc County.—Nequasset Brook with 430 acres is the only stream in this county (excluding the Androscoggin River) with over 40 acres of lake surface. The 15- to 18-foot concrete dam at tidewater has a well-designed masonry fishladder. The easy ascent provided by the series of large pools in this fishway is undoubtedly an important factor in the maintenance of the good run in this stream.

Kennebec County.—The only streams in Kennebec County proper are Cobboseecontee Stream, Nehumkeag Brook, and the main Kennebec River. According to Atkins (1887) alewives formerly ascended the Kennebec 91 miles to Norridgewock Falls and went some 20 miles farther up the Sandy River. The lakes of the Cobboseecontee Stream once afforded one of the principal breeding places for alewives of the Kennebec. The Nehumkeag Brook run (Atkins 1887) was destroyed by impassable dams in earlier years. We have no present information on this stream. In 1880, long after the main Kennebec had been closed by dams at Augusta and the Cobboseecontee by dams at Gardiner, the catch of the lower portions of the Kennebec (including Eastern River, Cathance Stream, Nequassett Brook and a few smaller streams) was 675,000 alewives. In 1867 the catch of this same area was estimated to have been 1,200,000 alewives for some years previous. No attempts at restoration of most of these tremendous alewife runs are feasible under present conditions.

Lincoln County.—Nine of the twelve streams of this county containing lake areas of over 40 acres were inspected. Of the remaining rivers, it is reported that the Goose River has no run, and there is some doubt as to the accessibility of the lake. Although we have no positive information it is improbable that the Eastern River or Deer Meadow Brook contain more than a few stragglers.

The Sheepscot River once had a good run, destroyed in the last century by a dam at Head of Tide. The wardens report that a few alewives still spawn in the short stretch of river below this obstruction. Dams farther upstream at Whitefield and Cooper's Mills have been abandoned—the dam at Whitefield is passable and the dam at Cooper's Mills was commencing to wash out in 1941. By building a fishway over the 12-foot concrete dam at Head of Tide, this river, containing over 2,800 acres of lake area, would be available for alewives and should be capable of supporting a large run. Atkins (1887) asserted that the Sheepscot River was once frequented by salmon and shad to a greater extent than any other river between the Kennebec and the Penobscot, so that any fishway over this dam should be designed to meet the minimum requirements for salmon.

The Dyer River has apparently always had an alewife run, which at present is too small to be of any commercial importance. The inspection, on May 12, 1943, showed the cause of the falling off of this run. The river is completetly blocked at the mouth of Dyer Long Pond by an old abandoned dam, without any sign of a fishladder. The crumbling ruins of an old mill astride this dam renders it very difficult to do any work on the dam. The dam is built chiefly of large loose rocks and at the time of our inspection a few alewives were observed trying, in vain, to negotiate the swift water rushing through the remains of the old dam. Since the 576 acres of lake area lie above this dam, since it is utterly worthless, and since a few alewives continue to come as far as the dam, it appears highly probable that a good run can be restored merely by clearing a passageway through the rubble and debris.

A small run in Lily Pond Stream was destroyed some years ago by a former fish screen at the outlet of the lake. It may be possible to reestablish this run.

Back River Stream is reputed to have once had a small run of alewives, which we do not recommend reestablishing, as Adams Pond is used as the water supply for Boothbay Harbor.

West Harbor Creek (Campbell's Creek) once had a good commercial run of alewives. The stream itself consists merely of a fishladder connecting West Harbor Pond with the sea. As this run was observed by Bigelow and Welsh (1925) the disappearance of the ladder must have been at some time within the past 15 or 20 years. The failure to maintain the ladder resulted in the complete extinction of this run. The Sea and Shore Fisheries Department replaced this fishladder in 1943, thus facilitating restoration.

The alewife fishery in the Damariscotta River was created about 1803 (Atkins 1887) when citizens of Nobleboro and Newcastle planted alewives in the lake and built a fishway over the falls. The run soon developed to commercial proportions and due to careful management has been the most consistent large commercial run in Maine. In the fifteen year period from 1866 to 1880 an average of 800,000 alewives were dipped from the river at Damariscotta Mills. In 1880, 1,700,000 were dipped at the Mills and an additional 2,300,000 were captured by weirs, gill nets, and seines in Bristol and Edgecomb. The latest figures of catch available (1942) show 1,050,000 pounds or approximately 2,000,000 alewives.

The Pemaquid River had an alewife run of some local importance which Atkins (1887) said was destroyed by impassable dams and improvident management. This run was apparently restored in later years. Smith (1899) gives the catch in 1896 as 206,000 fish or 115,875 pounds. The fishway over the dam at Pemaquid Falls was renovated in the fall of 1940. It now provides an easy ascent but it is doubtful if the present small run can become of much commercial importance with the present 50 acres (Boyd Pond) of spawning ground available.

However, a fishway over the 12-foot concrete dam at Bristol would provide an additional 2,750 acres. With this area available the Pemaquid should be able to support a run comparable in size with Damariscotta.

The alewife run in Muscongus Brook has dwindled to very small proportions due to a partial obstruction just below Webber Pond (253 acres) by large boulders that have fallen into the narrowed streambed at a former damsite. Efforts to clear a channel for the 1943 run were only partially successful. We recommend the complete removal of these boulders and the construction of one or two pools to aid the fish in surmounting the rapid at this point.

The Medomak River in 1896 produced 73,800 alewives or 41,512 pounds. A small run of alewives still ascends to the first dam, just above tidewater, and at times fish have been dipped over the dam in an attempt to keep the run from becoming extinct. Altogether there are four dams all without fishladders between the mouth and Medomak Pond, and below the two upper dams the river is choked with banks of sawdust and wood waste. All of these dams are too low to present any obstacle to the building of fishways, which we believe should be required. Ladders on this stream should be large enough to accommodate salmon.

Knox County.—Out of six streams in Knox County, with over 40 acres of lake surface, only the St. George River has any lake area at present accessible to alewives. The Megunticook River, the only other stream in this county with a large lake area (1,332 acres), is blocked by several dams at Camden. It is reported that Chickawaukie Pond (343 acres) on Mill River is used as a water supply by the City of Rockland. Vinalhaven Stream is reported to have a wooden dam four feet in height blocking a small alewife run from suitable spawning grounds. Sea and Shore wardens reported that the town is contemplating the building of a fishway over this dam. Inspection of Goose River disclosed that Hosmer Pond (80 acres) is rendered inaccessible to alewives by a long stretch of steep rocky ledges.

The St. George River has had a very excellent alewife run, but about the middle of the last century the gradual curtailment of the area of their breeding grounds by the closing of tributary lakes and the difficulty of passing the dams at Warren caused a decline in the number of the alewives (Atkins 1887). In 1880 the catch had fallen to 515,000 fish. In 1896 the catch was 686,000 fish or 385,800 pounds and in 1942 the catch was 324,000 pounds or approximately 650,000 alewives.

Waldo County.—Out of seven streams in this county with over 40 acres of lake surface only the Ducktrap River supports a commercial alewife run. The Goose River in Belfast has the largest lake area (1370 acres) but the stream is effectively dammed at the mouth for a power development that uses a very large and very long penstock

making it doubtful if this stream could be made suitable under present conditions.

The Passagassawaukeag River, which has 567 acres of lake surface, is obstructed at Holmes Mill about one mile from the mouth by a 10-foot concrete dam. A fishway over this dam wounld open Cross Pond with 162 acres. The main river is blocked one and one half miles farther upstream at Poor's Mill by a 7-foot masonry dam so constructed as to render installation of a fishladder comparatively easy. This fishway would open Sanborn and Dutton Ponds, with 122 acres. There are three other ponds totaling 248 acres on a tributary which enters the main river above Poor's Mill, but this tributary was not examined to determine whether or not it is passable to alewives.

Wescot Stream, entering Belfast Bay just east of the mouth of the Passagassawaukeag, is barred to alewives by a natural fall over bare rock ledges at its mouth. A fishway over this fall, which is only about five feet at the steepest part, would open up 50 acres of lake for alewife spawning grounds.

A few alewives ascend Searsport Stream a short distance above tidewater to a 12-foot wooden dam at U. S. Highway 1. The building of a fishway at this point would be rendered difficult because the mill has been built completely over the stream and the leakiness and disrepair of the dam might cause difficulty in operation. A fishway here would open up 50 acres for the spawning of alewives.

Marsh Stream is obstructed close to the mouth by a stone dam about ten feet in height, thus blocking 156 acres of lake area.

Marsh River or Colson Stream, with 155 acres of lake surface is said to be unobstructed, but has no commercial run.

Penobscot County.—The main Penobscot River and the three streams that enter the estuary of the Penobscot below Bangor have poor alewife runs. Alewives were apparently never very abundant in the main Penobscot (Atkins 1887) and today only small numbers ascend above the Veazie dam.

Souadabscook Stream, entering the Penobscot at Hampden, has 456 acres of lake area. There is an impassable 12-foot concrete dam a short distance from the mouth that was provided with a large concrete fishladder which appears to have fallen into disuse. The construction and location of this fishway are such that it should not have been expected to attract fish.

Alewives ascend Sedgeunkedunk Stream in small numbers as far as the dam in South Brewer. Until an examination has been made of the stream and tributary lakes no decision should be made as to the advisability of a fishway.

Mill Creek, South Orrington, has a small run of alewives of which a few are used locally. The 125 acres of lake area should support a much larger run under proper management. The smooth rock ledges and the abandoned concrete dam near the mouth present obstacles to the passage of alewives.

Hancock County.—Of the 22 streams in Hancock County with over 40 acres of lake area only 7 were found to be entirely devoid of alewives. There are several potential alewife streams awaiting restoration.

The Union River with nearly 32,000 acres of lake surface is reputed to have had an abundant run well over a century ago (Atkins 1887) but today the stream is blocked by a 60-foot concrete dam at Ellsworth.

The lake on Mill Stream in Bucksport is used as a water supply for the town and is not accessible to alewives.

The Orland River has an excellent alewife run which passes over two fishways into Alamoosook Lake. The fishway over the dam at tidewater is at present so short that fish can ascend only during the higher stages of the tide. The size of the run might be increased, if this ladder were lengthened and redesigned. The second ladder at Alamoosook Lake should have the exit redesigned to take care of different water levels in the lake above. At present the fish must struggle through under a head of water, often greatly delaying their passage.

Pierce Pond Stream, with 111 acres of lake, has no run. Although there are no permanent obstructions in the stream, the gradient is sufficiently steep, over large boulders, to make it doubtful if alewives can make the ascent.

Winslow Stream, with 125 acres of lake, has a poor run of alewives, which ascends about one and one-half miles to a 6-foot timber dam at the mouth of Wight Pond. The mill is built directly over the stream and mill waste chokes the stream bed below. A side stream from a wing dam enters the main stream about one hundred yards below the mill. A fishway was reported, but our inspection disclosed no evidence of it. It is recommended that a fishway be installed on the side stream and that the main stream be barricaded where the side stream enters it to guide the alewives into the fishway.

The summer flow of Parker Pond Stream (with a 52-acre lake) was reported by the Inland Fisheries warden to be very small, and therefore it is probably unsuitable.

Walker Pond Stream is extremely short, connecting Walker Pond (697 acres) with the Bagaduce River, an arm of the sea. This stream formerly supported a heavy run of alewives, that has declined to small proportions, apparently due in large measure to failure to maintain the proper conditions in the fishway over the dam at the outlet of the pond. When inspected, the fishway, consisting of a side stream which joins the main stream below the mill, was choked with sawdust and mill waste. No barricade was provided in the main stream to guide alewives into the side stream and no provision was made at the exit of the fishway to adjust for different levels of water in the pond.

Carleton (Allen Mill) Stream with four ponds totaling 411 acres, is undoubtedly the stream in Bluehill mentioned by Atkins (1887) as once supporting an alewife fishery, which had long disappeared by 1880. A few alewives still enter the stream, which is blocked about one-quarter of a mile from tidewater by a stone dam about six feet in

height. The mill at this point is built over the stream, so that the construction of a fishladder would be extremely difficult. The stream below the mill is almost entirely choked with banks of sawdust and mill waste.

Patten Stream is reputed to have once had a good run of alewives, but as long ago as 1880 the run had dwindled to less than commercial levels owing to obstructions offered by dams (Atkins 1887). Inspection reveals clearly that the decline in this run is caused by failure of the alewives to reach the excellent spawning grounds (1102 acres) afforded by Lower and Upper Patten Ponds, in spite of supposedly effective fishladders. The first dam, two miles from tidewater, built of lumber and about six feet in height was inspected in March 1943. The fishladder at this dam is flimsily constructed, poorly designed, wholly inadequate for the proper passage of fish as large as alewives, and at the time of inspection was completely clogged with sawdust and mill waste. The second obstruction is composed of a main dam and a wing dam at the outlet of Lower Patten Pond. The upper end of the fishladder in the main dam is located in such shallow water that the ladder becomes dry when the water level in the lake falls slightly, as it is bound to do in dry weather, owing to bad leaks in the wing dam. The lower end of this ladder is poorly located to attract fish. Even at the time of inspection, in March 1943, the water level of the lake was so low that most of the water was escaping through leaks in the wing dam. The wing dam should be made water-tight and the fishladder in the main dam redesigned and relocated.

Taunton (Mill) Brook and Card Mill (Hog Bay) Stream in Franklin, unobstructed streams, with 345 and 715 acres of lake respectively, both support commercial runs of alewives.

Flanders Stream was once obstructed by two dams and a fish screen below Flanders Pond (555 acres). All these obstructions have disappeared. As there is no run in this stream at present, it offers an opportunity for restoration.

Morancy Stream has only a 60-acre pond but the stream itself is of fair size. If there was a former alewife run it was undoubtedly destroyed by a fish screen, which has since rotted away. This stream offers an opportunity for restoration.

Jones Stream with a pond area of about 360 acres has had an alewife fishery since about 1880. This run, started by artificial stocking, is maintained by placing a portion of each year's run in the lake.

Prospect Harbor Stream has a poor run of alewives today, but once had a much better run. This run could undoubtedly be rebuilt under careful management.

West Bay Stream has a fair sized lake area (300 acres) in West Bay Pond, with a wooden dam seven feet in height at the outlet. A ledge at one end of the dam would make it easy to install a fishladder and since the dam is used only to maintain the water level, operation of the fishway would be simplified.

Chicken Mill Stream has no run, but an artificial pond of about 50 acres impounded by an 8-foot stone dam could be used for alewives, if a ladder were constructed.

Seal Cove Brook on Mount Desert Island drains two ponds totaling 315 acres. A few alewives ascend the brook about 200 yards to a point where the remains of an old dam blocks the stream. The removal of this obstruction would permit the reestablishment of the run.

Denning Brook in Somesville drains 244 acres. A few alewives ascend three-quarters of a mile to an 8-foot masonry dam with a drop of four feet at the spillway. As the dam is used only to create an artificial pond it can easily be made passable by the construction of two or more pools across the main stream.

Great Pond Stream drains the largest lake area (1053 acres) on Mount Desert Island, and it is reported to have a fair alewife run. The stream has a concrete dam at tidewater about four feet in height with a steep beach below it. A large concrete fishladder has been provided but at the time of inspection the edge of the lower pool was broken.

Hadlock Pond Stream has such a small flow that it is probably not suitable for alewives.

It is reported that a few alewives ascend Jordan Stream, which has 211 acres of lake area. We were informed and our inspection confirmed that during the summer low-water periods the stream becomes so diffused through the sea wall and gravel bars at the mouth that it is impassable.

Washington County.—In this county there are 10 rivers with over 40 acres of lake area. These 10 streams have 46,811 acres of lake surface, of which 28, 407 acres on three streams are more or less accessible to alewives.

Tunk Stream is blocked about ten miles from the mouth by an 8-foot dam at Unionville. Construction of a fishladder at this point would open over 3,200 acres of lake area for alewife restoration.

The alewife run in the Narraguagus River was destroyed a great many years ago by several dams at Cherryfield. The destruction of these dams by ice in 1942 opened up considerable lake area but further inspection of natural obstacles will be necessary to determine which lakes are now accessible.

The Pleasant River (860 acres) is reported by Atkins (1887) to have had a large alewife run about 1820. Later the run was stopped by the dam at Columbia Falls and it declined until the catch was about 30 barrels per year by 1880. A small run continues to spawn below the dam at Columbia Falls.

The Machias River has a small run of alewives, but they are not sufficiently numerous to be taken commercially. According to early reports (Atkins 1887) they were never as abundant in this river as in the East Machias, owing perhaps to the very difficult natural falls at the head of the tide. With over 9,500 acres of lake available for

spawning this river should support a very large run of alewives if these falls were made passable.

The East Machias River with the largest lake area accessible to alewives of any of the streams in Maine, has a good alewife run. In 1942 it produced 693,000 pounds, second only to Damariscotta.

The Orange (Whiting) River with nearly 1,900 acres of lake area is rendered inaccessible to alewives by high concrete dams at the mouth.

The Dennys River with 9,000 out of 10,700 acres of lake area accessible to alewives has a fair run. This run has never been exceedingly large within the last century due to dams that existed in the river at various times, and amounted to only 126,000 pounds in 1942. This run undoubtedly could be greatly increased by proper management, especially by keeping open the fishway into Meddybemps Lake.

The Pembroke River once had an excellent run of alewives according to Atkins (1887) but today the 1,900 acres of spawning grounds are blocked off by impassable dams at the mouth.

Restoration by means of Stocking

The survey has shown a considerable number of Maine streams from which alewives have been eliminated. The first step in returning these streams to productivity is the re-establishment of a run. The second step, discussed under management, is the provision for self maintenance of this run by the diminution of detrimental pollution and the assurance of free passage between the sea and the lake areas needed for adequate spawning and nursery grounds.

In no known case in which the alewife run to a stream has been completely destroyed, have the alewives become naturally reestablished. (Belding 1921, and Bigelow and Welsh 1925). Many cases, however, are recorded, in which the planting of adult alewives in such a stream has resulted in the reestablishment of a run. (Belding 1921).

Several streams were selected for stocking with adult alewives during the 1943 run. Due to the shortage of manpower and gasoline these streams were selected partly on their distance from the Fisheries Stations at Boothbay Harbor and Craig Brook from which the stocking trucks were operated. The truck from the Craig Brook Station was supplied and operated by the U. S. Fish and Wildlife Service and the other by the Maine Sea and Shore Fisheries Department. A biologist from the Fish and Wildlife Service accompanied each truck to supervise and aid in distribution.

These trucks held about 500 gallons of water when filled to the proper level for carrying fish and were fitted with compressors, to aerate the water. The adult alewives were obtained from the Damariscotta and Orland Rivers, by dipping them from the stream into wash tubs or directly into the tanks. Care was taken to dip only a few fish at a time to prevent the weight of the top fish from injuring those underneath.

TABLE 7.—*Alewife stocking in Maine streams during 1943*

Stream stocked	Date	Place planted	Temperature		Number of alewives			
			Where loaded	Where planted	Carried	Died	Stocked	Stream total
Sheepscot River	May 20	Sheepscot Pond	58°F.	60°F.	425	125	300	......
Do.	21	Do.	58	58	546	164	382	682
Lily Pond Stream	25	Lily Pond Stream	58	63	425	37	388	388
West Harbor Creek	17	West Harbor Pond	....	....	475	6	469	......
Do.	19	Do.	58	63	334	217	117	......
Do.	20	Do.	58.5	60	511	8	503	......
Do.	21	Do.	57.5	59	468	8	460	......
Do.	24	Do.	58	64	704	284	420	1,969
Pemaquid River	12	Pemaquid Pond	52	....	429	1	428	......
Do.	25	Do.	57	65	469	14	455	883
Medomak River	19	Medomak Pond	58	60	768	578	190	......
Do.	24	Do.	58	63	498	127	371	561
Winslow Stream	18	Wight Pond	58	68	318	3	315	......
Do.	19	Do.	58	65	260	0	260	575
Carleton Stream	18	Second Pond	58	59	235	8	227	......
Do.	18	Do.	58	59	453	105	348	......
Do.	20	Do.	60	65	256	15	241	816
Flanders Stream	21	Flanders Pond	59	55	260	0	260	260
Morancy Stream	24	Morancy Pond	60	54	280	5	275	275
West Bay Stream	25	West Bay Pond	62	64	312	1	311	311
Seal Cove Stream	19	Seal Cove Pond	58	60	250	12	238	238
Denning Brook	20	Echo Lake	60	58	256	16	240	240
Tunk Stream	25	Tunk Lake	64	64	312	12	300	300
Totals	....	....	....	....	9,244	1,746	7,498	7,498

Where conditions permitted the fish were released directly into the ponds instead of into the stream. The truck was driven close to the pond, the fish dipped directly into the pond or carried in buckets or wash tubs filled with water, and counted with a hand tally as they were released. After release any that appeared injured or weak were removed and subtracted from the tally of live fish.

The temperature of the stream was taken at the time each truck was loaded. No difficulty was encountered, because of the temperature, for the first few loads handled, but as the weather became warmer it was found necessary, when hauling larger loads, to keep the temperature in the tank a few degrees lower than that of the stream from which the alewives were taken, by the use of ice.

Table 7 shows the streams stocked, losses enroute, temperature of the streams, etc. A total of 9,244 fish were carried, 1,746 fish died enroute or while planting, making a total of 7, 498 adult fish, ready for spawning, planted in 13 streams. West Harbor Creek received the heaviest stocking (1,969 fish) because of its proximity to Boothbay Harbor, where one of the trucks was garaged.

The alewife has a very high fecundity, Belding (1921) estimated the number of eggs from 60,000 to 100,000 per female. That the survival of the young must be quite high is evidenced by the artificial maintenance, for over a century, of a commercial run in Jones Stream (West Gouldsboro) by planting about ten percent of each year's run in Jones Pond for spawning. Our observations of runs in other streams lead us to believe that the escapement in most streams with commercial runs does not average much higher. Therefore, although the number of adult fish hauled was not large, we have confidence that results will be secured.

Evidence that the alewives which were planted spawned successfully has already been demonstrated at West Harbor Creek. In July dense schools of small alewives, appearing to number in the hundreds of thousands, resulting from the stocking of the adults planted in West Harbor Pond during May, were seen passing down the newly constructed fishladder into the harbor.

Management of Alewife Runs

Introduction.—Given a stream with a sufficiently large area of quiet water for spawning and for the development of the young, and a sufficient flow to maintain a downstream passage for the young during late summer, an alewife run, once established, should not be difficult to maintain. Of course detrimental pollution must be abated, and all artificial or natural obstructions to the migration of the fish must be made easily passable.

Having assured the fish unobstructed passage to and from suitable spawning grounds, the most important remaining problem is a guarantee that a large enough proportion of each year's run will be allowed to escape through the fishery to form a brood stock.

Except perhaps for a very few streams in highly industrialized localities, our observations do not lead us to believe that pollution has been an important factor in the decline of the alewife runs in Maine. This leaves two factors that account for most of the difficulties encountered in maintaining a successful run; namely, obstructions to migration, and the failure to permit an adequate number of adults to escape through the fishery.

Obstructions to migration.—Natural obstructions occur on very few of the streams inspected and most of those observed could be easily made passable.

Except for fish screens, all artificial obstructions observed were due directly or indirectly to dams. In many cases, streams are blocked by dams long since abandoned by the owners. There is no logical reason why such abandoned structures should be permitted to interfere with the proper utilization and maintenance of our fisheries resources. Anyone holding title to such an abandoned structure should be required either to open a passageway through the dam or to permit similar action by others.

Dams which are still in active use present a more serious problem due to fluctuations in water levels, to temporary drying up of stream beds, to the danger of destroying fish migrating downstream by water wheels, turbines, and pumps, and to the use of the entire stream flow, leaving none for use in a fishway.

Many of the fishways observed were poorly designed, constructed, and maintained; therefore, since several fishways must be built to accommodate the runs returning from the stocking program now under way, they will be discussed in some detail.

The basic requirements of a successful fishway are that it shall provide a passageway over the dam for the various types of migratory fish in the particular stream at any water level or volume of stream flow. Furthermore, the fish must be able to make the ascent without injury or exertion of extreme effort and must not be unduly delayed at the barrier while searching for the fishway entrance. To meet these requirements particular attention must be paid to certain features of location and design.

The entrance of a fishway, if located too far downstream from the barrier, will be passed unnoticed by the fish, which tend to follow the main channel until barred by the dam. If they find such an entrance at all it is often found only when drifting downstream, exhausted or injured, after fighting in vain to pass the obstruction. Therefore, the entrance should be located very close to the foot of the dam. If the dam is built obliquely across the stream, the entrance to the fishway is usually best located at the upstream end. One of the primary requirements for attracting fish into the ladder is that the entrance shall be located sufficiently close to the main current from the spillway or tail race so that fish following this current will almost automatically find themselves at the entrance. If the entrance is thus strategically

located so the the fish arrive there, then inducing them to enter is largely a matter of providing a sufficient flow of water. The volume necessary to attract them will depend to a great extent on the volume of the main stream.

The most popular type of alewife ladder observed is merely an inclined sluiceway, in which the water is supposed to be somewhat retarded by a series of baffles extending alternately from each side of the flume. This type is entirely unsuitable for a dam of any height, for, unless the incline is very gradual, the water rushes through at high speed. Furthermore, unless the dam is very low, the entrance is apt to be too far downstream.

Fish have less difficulty ascending a series of pools connected by low falls or short rapids. The consistent success of the Damariscotta alewife fishery is probably due largely to this type of ladder. Where it is impractical to construct pools of natural rock or masonry, a series of wooden or concrete boxes may be substituted—such a ladder is depicted in Figure 1. The drop between boxes should not exceed twelve to sixteen inches. The size of the pools can vary somewhat in accordance with the size of the stream and of the run that must be accommodated. In streams with a good run, the boxes should be not less than six feet long, four feet wide, and four feet deep. If the ladder is also to accomodate salmon, it is desirable to increase this size somewhat, thus a box eight feet long, six feet wide and six feet deep provides a ladder of ample proportions.

It will be noted in the sketch of the fishladder (Figure 1) that provision has been made for differences in the level of the water in the forebay, by building two pools parallel with the face of the dam. If the dam is very high or subject to great fluctuations in water level, this number may have to be increased. The exits are provided with stop logs, so that the flow can be readily adjusted. Many dams, instead of stop logs have a gate setting on the bottom of the opening, that can be raised to allow water to pass the fishway by flowing under the gate. This method of regulating the flow has certain definite disadvantages. If the gate extends deep enough to provide water for the fishway when the level in the forebay is low, the opening is so deeply submerged at high water levels that the fish must force their way through the opening under the gate against a considerable head of water. Furthermore, with the increased pressure at high levels the opening must be made so small, to compensate for increased velocity that the space is usually too small. We have seen several otherwise good ladders, that were difficult for fish to pass because of this undersirable feature. The pool type of ladder is especially desirable for streams with a very small summer flow, as it can be run efficiently with less water.

It would be helpful in preventing the building of unsuccessful ladders, if a fisheries biologist and an engineer were consulted on the design and location of each fishway previous to starting construction.

From the foregoing it should be apparent that adequate passage

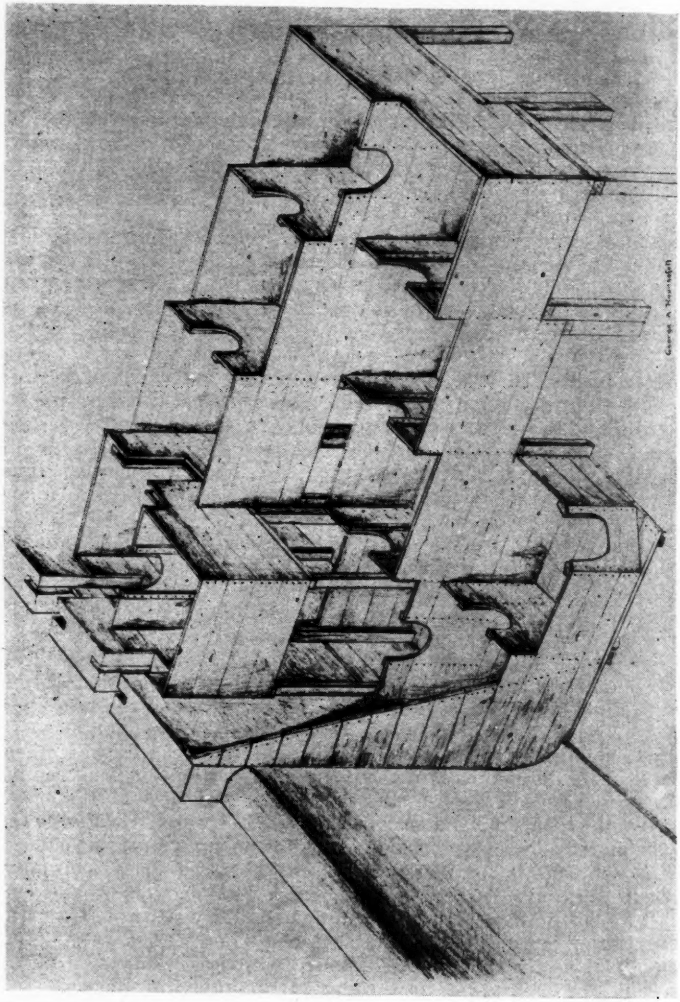

FIGURE 1.—Sketch of a pool-type fishway designed to pass alewives over a 12-foot dam.

cannot be assured merely by providing a fishway. Responsibility for the operation, inspection, maintenance, and repair of each fishway must be definitely assigned to responsible parties. In addition it is suggested that State fishery officials make at least an annual inspection and report on the condition of each fishway.

Provision for an adequate number of spawners.—In unobstructed streams suitable for alewives it is doubtful if many runs have been entirely destroyed by overfishing, but it appears certain that many runs have been kept at an unproductive level by failure to permit an adequate number of adults to spawn. If too few spawners escape to the spawning grounds there will be insufficient young produced, but, on the other hand, if a very large number spawn the survival rate will undoubtedly be lower. Thus it is economically wasteful to permit either too few spawners, or more spawners than are needed. The number of spawners that will, on the average, allow the largest fishery is a problem to be solved for each stream, and can only be ascertained by careful records and observations over a number of years.

Since the conditions of survival vary somewhat from one river to another one cannot assume that the proportion of the run that should be allowed to spawn in one stream is necessarily the best proportion for another. In the streams recently stocked it may be possible in several instances to obtain accurate estimates of the number of adults surviving, which will yield some basis for calculating the proportion of spawners needed to maintain a run. However, these figures will be based on survival with a minimum number of adults. As a general rule the survival rates decrease as the population increases so that the number of spawners required as shown by this evidence may be insufficient to maintain a run that approaches the real capacity of the stream.

Since the accurate determination of the best number or proportion of adults needed for spawning is a complex matter, the solution of which requires accurate knowledge of catch and number of spawners over many years it is obviously impractical to gather this information for each of the multitude of streams involved. It would be well worthwhile, however, to commence the collection of data bearing on this problem for the chief alewife rivers.

Since no information exists on the actual number of spawners that have been permitted to ascend any of the alewife streams, the only course that can be followed at present is to attempt to assure an adequate number by following practices that have been proven successful and by keeping accurate records of the catch and factors affecting it.

One practice that may be largely responsible for curtailing the number of spawners below the economic level is permitting weirs and seines to be fished in salt water in the narrow estuaries of some of the streams. These may take a heavy toll of the fish before they reach the stream, where they are then subjected to the regular town fishery.

FIGURE 1.—Sketch of a pool-type fishway designed to pass alewives over a 12-foot dam.

This practice is unfair to the town that tries to maintain a successful fishery, since the town must maintain the fishways, operate them, and see that a fair proportion of the run escapes to spawn. This double toll should be eliminated insofar as possible so that the agency running the fishery can exercise full control of the catch.

The method used in taking the fish may have a considerable influence on the amount of the escapement. In some of the smaller streams the fishways may be entirely closed on days when fishing is being conducted. If the fishway is then left open for the full 48 hours of Saturday and Sunday, as provided by State law, and no nets or other obstructions are used to hinder their ascent, a fair escapement may be provided. However, this method has certain disadvantages. Alewives do not run steadily, but even during the height of the run may stop entering a stream for two or three days at a time if the weather turns cool. In order to be certain of sufficient escapement under the usual method of fishing in which the numbers permitted to pass are not accurately estimated, the fishways should be left open at all times. At Damariscotta the fishway is a series of natural pools forming a stream that reenters the main stream below the dam. This side stream is always open and no fishing is permitted in it.

Probably the chief cause of overfishing is the leasing of a stream to a company or private individual, which does its own fishing. The best procedure is for the town to do the fishing, with proper regard for a brood stock, and then sell the fish taken.

The ideal situation would be to have all fish pass through the dipping pool. Then the town fish committee could let a certain proportion of the fish escape by releasing every third, fourth, or fifth poolful throughout the run. Then by keeping records of the number of fish caught it would be possible to estimate quite accurately the actual number of alewives permitted to spawn each year. After a number of years the committee would be able to estimate the best number of spawners for that stream. With this knowledge the proportion allowed to spawn could be changed from year to year in accordance with the size of the run, so that a larger share could be caught from large runs and a smaller share from small runs.

Recommendations

The streams listed in Table 8 should be made passable for alewives. Nine of the streams listed were stocked wth alewives in 1943 and 3 of the remainder will require stocking to get runs reestablished. The streams are listed roughly in accordance with our opinion of their importance to the program. This was based on the area to be made available, the volume of stream flow, and the probable relationship between the expense of the work and the size of the runs to be expected.

TABLE 8.—*Recommendations for action on stream obstructions listed approximately in the order of their importance*[1]

Stream	Location of obstruction	Type	Approximate height	Lake area to be made accessible	Recommended action
			feet	*acres*	
Pemaquid River	Bristol	Con. dam	12	[2]2,753	Fishway.
Sheepscot River	Head of Tide	Con. dam	12	[2]2,311	Fishway.
Tunk Stream	Unionville	Log dam	8	[2]3,047	Fishway.
Patten Stream	2 miles from mouth	Wood dam	6	....	Redesign and rebuild present fishway.
Do.	Outlet Lower Patten Pd.	Wood dam	5	1,102	Redesign and rebuild present fishway, repair leaks in wing dam.
Dyer River	Outlet Dyer Long Pd.	Stone dam	4	576	Clear away remains of old dam.
Saint George River	Union Village	Log dam	4	....	Fishway.
Do.	Outlet Sennebec Pd.	Con. dam	12	602	Fishway.
East Machias River	Outlet Gardner Lake	Con. dam	10	5,584	Fishway.
Pleasant River	Columbia Falls	Wood dam	10	860	Modify ladder for alewives.
Seal Cove Brook	Tremont	Old dam	3	[2]315	Clear away remains.
Denning Brook	Somesville	Stone dam	4	[2]244	Fishway.
Muscongus Brook	Outlet Webber Pd.	Boulders	Rapid	253	Clear streambed, construct pools.
West Bay Stream	Near Gouldsboro	Wood dam	7	[2]300	Fishway.
Carleton Stream	Bluehill	Stone dam	6	[2]411	Fishway.
Winslow Stream	Outlet Wight Pd.	Wood dam	6	[2]125	Fishway.
Medomak River	Waldoboro	Log dam	6	....	Fishway.
Do.	Winslow Mills	Stone dam	10	....	Fishway.
Do.	Below Medomak Pd.	Stone dam	12	....	Fishway.
Do.	Below Medomak Pd.	Wood dam	5	[2]320	Fishway.
Passagassawaukeag River	Holmes Mill	Con. dam	10	162	Fishway.
Do.	Poors Mill	Stone dam	7	122	Fishway.
Royal River	Yarmouth	Con. dam	7	....	Fishway.
Do.	Yarmouth	Stone dam	9	250	Fishway.

1 See text.
2 Stocked with adult alewives in 1943.

The stocking program should be continued for a full cycle of four years in each stream selected for stocking in order to establish a run on every year of the alewive's four-year age cycle.

Someone should be given full responsibility for the operation and maintenance of each fishway. State fishery officials should make a detailed inspection and report on each fishway at least once a year. All fishways should be checked by a biologist during the up- and downstream alewife migrations to determine their efficiency.

Accurate records of the catch should be obtained by the State for each stream at the close of the alewife fishing season.

To encourage the practice of adequate management measures by the towns controllng the alewife fisheries, the use of weirs and seines for the capture of alewives near the mouths of the rivers should be discouraged.

Summary

The results of former alewife plantings, coupled with scale readings from three rivers, indicate that the age at maturity is probably four years in Maine and three years in southern Massachusetts. Thus the first returns from the 1943 Maine stocking are expected in 1947.

Analysis of the data from the survey of Maine streams shows that there is a high positive relationship between the size of the run to a stream and the lake and pond area accessible for spawning and for the development of the young.

The chief factors limiting alewife production in Maine are impassable dams, poorly designed and maintained fishways, and overfishing.

Thirteen streams were stocked with 7,498 adult alewives during the 1943 run. Observations at West Harbor Creek indicate that the adults reproduced successfully.

Excluding the four larger rivers, the Androscoggin, Kennebec, Penobscot, and St. Croix, the survey showed 162,717 acres of lake area on streams between Kittery and Calais. Of this total, 78,558 acres of lake area lie on seven streams with high power dams and industrial development that render it somewhat doubtful if the cost of making these streams suitable is justified for alewives alone. An additional 876 acres were found unsuitable and on 4,013 acres no information was obtained.

Of the remaining 79,270 acres of potential alewife lakes, only 28,932 acres, or 36.5 percent, on ten streams are supporting the regular alewife fisheries. Runs that are not sufficiently abundant to be exploited commercially occur on 11 additional streams with 12,332 acres of lake area. The runs to seven of these streams, with 2,156 acres, can be improved by proper management, and, in some cases, by the modification of fishways and the removal of obstructions.

The 29,000 acres now producing good runs can be increased by 19,337 acres of suitable area, now wholly or largely inaccessible, by carrying out the recommendations for stream improvement listed in Table 8 in conjunction with a program of stocking for those streams that are now devoid of runs. An additional 837 acres of accessible area on four streams, from which alewives were eliminated by former obstructions, were restocked for the first year of the four year cycle in 1943. When the necessary stream improvements are made and the runs reestablished the alewife spawning areas now supporting the regular commercial fisheries will be increased by 70 percent.

It is the opinion of the authors that the production from the alewife runs in Maine can be easily doubled by carrying out the suggestions embodied in this report in regard to fishways, natural obstructions, management methods to guarantee an adequate annual spawning stock, and by continuation of the stocking program.

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NOTE CONCERNING THE COMMISSION OF CERTAIN APPENDICES

It has been customary for the Society to publish in each volume of the *Transactions* the following apendices:

1. Certificate of incorporation.
2. Constitution and by-laws.
3. List of members.
4. Instructions for preparing and editing manuscripts.

These appendices have been omitted from the present volume in order to conserve printing funds and because the number of members in the armed services and on special war duty away from their customary places of residence have rendered almost impossible the preparation of an up-to-date and reliable list of members and addresses.

Publication of the appendices listed above will be resumed in Volume 74.

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